The Modern Relay

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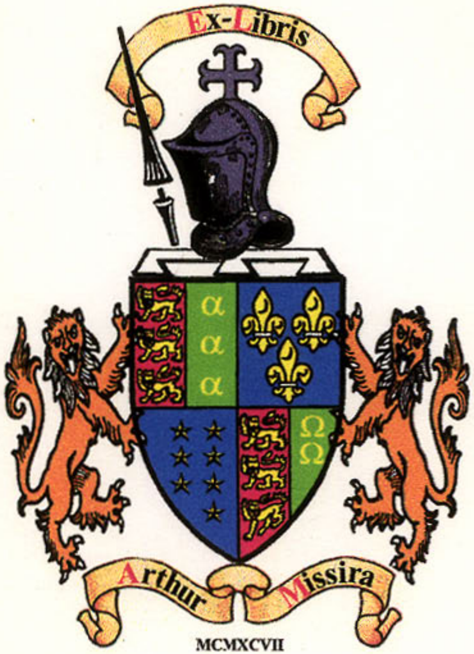
Using cybernetic development methods to achieve the ultimate in technology

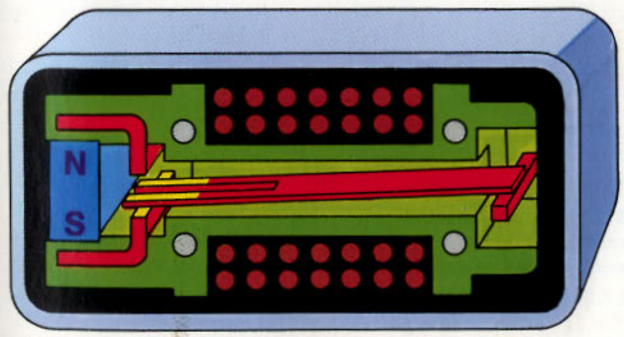
SDS-Relais



The Modern Relay

Using cybernetic development methods to achieve the ultimate in technology

By Joseph Eichmeier



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The illustration overleaf shows a sectional view of an SDS R-relay, heralding a new era in modern relay technology.

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Contents

Development, Purpose and Significance of Modern Relays

In 1837, when Samuel Morse, using the electromagnet invented by J. Henry in 1824 first made his "writing telegraph" operate, the birth of the relay took place. Anyone talking of *relays* in those days – the days of the mail coach – would, however, have been thinking of a change of horses.

Five relays in use "per person"

Today, there are an estimated 25,000 million relays in operation worldwide (approximately five for every person on earth). These relays carry out switching control and monitoring functions in electrical systems, devices and equipment at around 25 million operations per second.

Signals applied to the coil can be amplified in the contact circuit by a factor of up to 10^5, or reduced by up to 10^{-10}. Time delays lasting from milliseconds to many hours can be achieved, as well as branching the signal over several contact circuits.

Fig. 1 (opposite): Modern relays of the electronic age are found in an unexpectedly large number of different applications. The sectioned relay in the centre of the picture has a height of 5.2 mm and weighs 1.4 g

The safety and efficiency with which this multitude of switching functions are carried out (around a million per second in the Federal Republic of Germany alone) are of importance to the economy of every country. It is therefore worth studying relay technology in greater depth. It will then be evident that relays are interesting, complex structures, in which, in addition to electromagnetic and mechanical influences, a range of different

factors also operate. Activating and tuning these many influences, one to the other, is a factor that was neglected during the development of conventional relay technology. This is confirmed by publications in which such relays were presented as mature designs and their technology as fully developed. And yet, this seemingly outdated relay technology, which some even referred to as dead, displayed the capability of being greatly improved both technically and economically together with simultaneous miniaturization.

Living technology

This is illustrated by the comparison of the modern TQ relay (or even the TQ + C-switching circuit), with the 160 times larger relay type F 48. Approximately 50 million of the latter are still in operation in German telephone exchanges and contribute to making waiting periods on average 12 seconds longer than would be necessary if relays using today's technology were installed instead. To illustrate the point, who would give any consideration to the

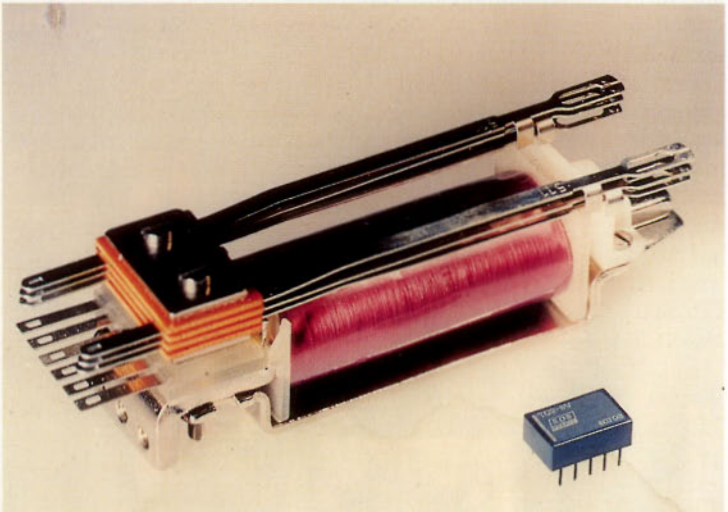


Fig. 2: A traditional technology telephone relay (type F 48 above) and a 2nd generation relay (here type TQ from SDS). Comparison data is given in table 1

Type (with 2 changeover contacts)		F 48	TQ	TQ+C
Relay generation		first	second	third
Year of first manufacture		1960	1986	
Volume	cm^3	100	0.6	0.85
Power consumption	mWs	250	140	0.3
Load switching range	VA	10^{-3}...150	10^{-9}...100	
Pick-up + bounce time	ms	20 + 5	2 + 1	1 + 1
Operational life at 1W	sw.ops.	$2 \cdot 10^7$	10^8	
Price guideline for 1000 pieces	£	approx. 17	1.90	2.60

Table 1: Comparison of data for the F 48 relay with the SDS type TQ reveals that the idea that miniaturization increases power consumption and production costs does not hold for 2nd and 3rd generation relays

fact that these 12 seconds taken over 30.4 billion calls per year (excluding misdialling etc.) add up to around 101 billion hours and thus cost the national economy of Germany alone, (assuming 75% are business calls and an average salary level of DM 50 per hour) more than 3.8 billion Deutschmarks (£ 1.2 billion) per year? In addition to this hidden cost there are the considerably higher investment and operating costs, which in Germany amount to approximately five thousand million Deutschmarks (£ 1.6 billion). The development of modern relay technology was not an act of magic which overcame an apparently insurmountable barrier. The revolutionary advances in modern relay technology were in fact the result of an interdisciplinary, cybernetic approach used in developing these products. The DABEI Handbook mentioned on page 71 explains these cybernetic methods more closely.

Structure and Part Functions of Electromagnetic Relays

Cybernetic interaction

In electromagnetic relays there are not only mechanical phenomena but also interactions of thermal, technological, chemical, and, more recently, electronic influences as well. The better these are optimized and tuned one to the other, the more efficient will be the operation of the relay. For specific applications, the number of part functions optimally tuned to one another, can haye an exponential effect on the efficiency (see page 30).

1st Generation Relays

Basic part functions

Conventional type relays have five part functions, which we will now briefly summarize.

First part function

Conversion of Electrical Current into a Magnetic Flux

Each current-carrying conductor induces a *magnetic field*, the direction and strength of which is described by continuous magnetic *lines of force*. The density of lines of force at any location is an indication of the field strength at that point. The total of the magnetic field lines is called *magnetic flux*. Fig. 3 shows the lines of force or magnetic flux Φ and the often neglected, ineffective stray flux Φ_s of a coil (1) with ferromagnetic core (2) and yoke (3). Since the ferromagnetic resistance of ferromagnetic materials is an order of magnitude lower than that of air, the magnetic flux flows mainly within this material. However, the resistance of the ferromagnetic material

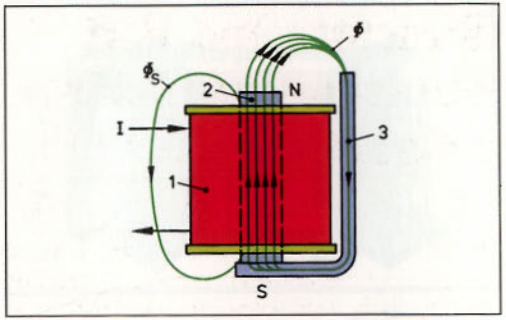


Fig. 3: Magnetic flux Φ of a coil (1) with ferromagnetic core (2) and yoke (3). The end of an electromagnet which has flux leaving it is described as North, plus or N pole and the end with flux entering as South, minus or S pole. I = excitation current

increases as the flow density increases, until magnetic saturation is approached, where it then approximates to the resistance of air. The stray flux then increases correspondingly. These considerations, again, did not receive sufficient attention during the development of conventional relays. There is no stray flux in the centre of a coil. Thus it is often expedient to mount the armature (5) in the centre of the coil, as shown in fig. 7.

Second part function

Converting the Magnetic Flux into a Force

If the illustrated coil is supplemented by a pivoted armature (4), then the core will exert a force of attraction, F, on the armature. The

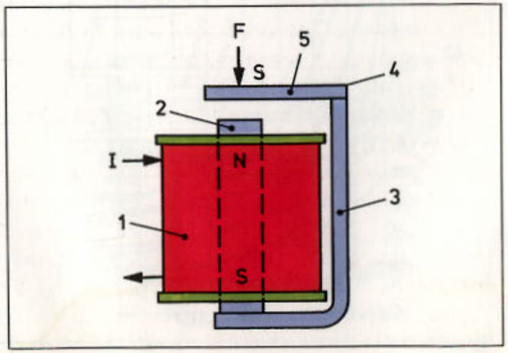


Fig. 4: The electromagnet shown in fig. 3 has added to it a moving armature (5), which is attracted with a force F to the core. A change in current direction changes only the electromagnet polarity

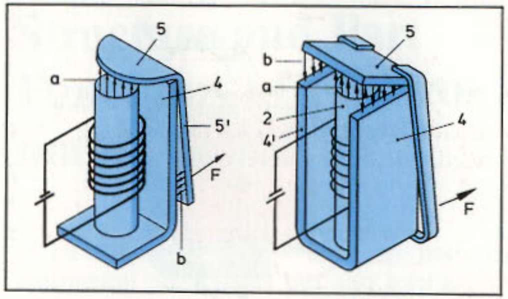


Fig. 5: Traditional magnet system. Left with an effective working airgap "a" and a contra-acting, force-reducing airgap "b". Right with two effective working airgaps "a" and "b"

possibility of utilizing the magnetic flux will then be: poor (fig. 5, left); adequate (fig. 4); good (fig. 5, right); or optimal (fig. 7).

The more than doubled forces of attraction of the twin airgap system (see fig. 6), result from double the utilization of the effective flux at gaps (a) and (b) and from the reduction in stray flux, brought about by the two legs of the yoke (4) and (4′). The curve X (fig. 6) illustrates the movement distance S, where the single airgap system is more favourable.

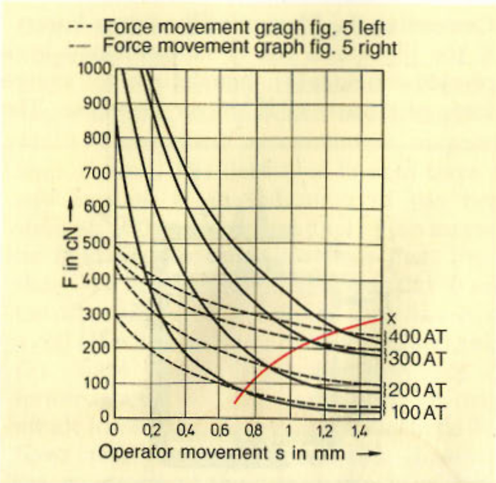


Fig. 6: Force/movement diagram of magnet systems shown in fig. 5 (volume approx. 18 cm³) with a current flow of 100, 200, 300 and 400 ampere turns (AT)

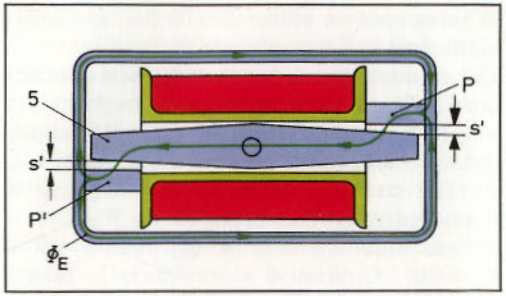


Fig. 7: Section through a magnet system which has its armature A pivoted in the coil centre, symmetrically between poles P and P′ and screened with a ferromagnetic cover

In the magnet system shown in fig. 7, there is no significant stray flux with the armature mounted in the centre of the coil, and very little stray flux through the ferromagnetic cap which carries the excitation flux Φ_E and encloses the system.

Third part function

Conduction of Mechanical Energy to the Contacts

In order to transfer the armature attraction force F to the relay contacts, a contact spring (7) (which also carries the contact parts (8) and

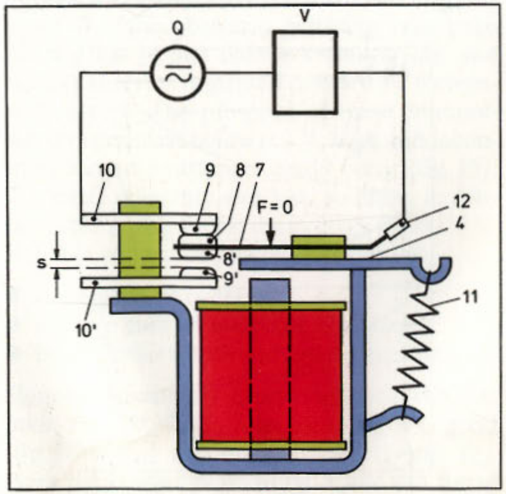


Fig. 8: Circuit based on fig. 4 with the addition of relay contacts 8, 8′, 9 and 9′; contact spring 7; connections 10 and 10′ and reset spring 11. The power supplied from the power source Q to operate device V is to be switched on and off by the relay

(8′) mounted on either side of the free end), is attached to the armature.
The contacts (9) and (9′) with their connections (10) and (10′) are mounted opposite (8) and (8′). On excitation of the relay, both armature and contact spring move from 9 to 9′. The contacts move by the distance of contact travel s. This opens circuit 7 – 8 – 9 – 10, and simultaneously closes circuit 7 – 8′ – 9′ – 10′. Contact 8 – 9, which is closed without any excitation, is known as the *normally closed contact*. Contact 8′ – 9′, which is closed by excitation, is designated the *normally open contact*. It is possible for several contact sets to be operated simultaneously.

Fourth part function

Storage of Mechanical Energy Required for Contact Opening after Cessation of Excitation

During the excitation of a relay, simultaneously with the movement of the armature and the contact spring, a reset spring (11) is tensioned with a resultant storage of mechanical energy. When excitation ceases, this energy

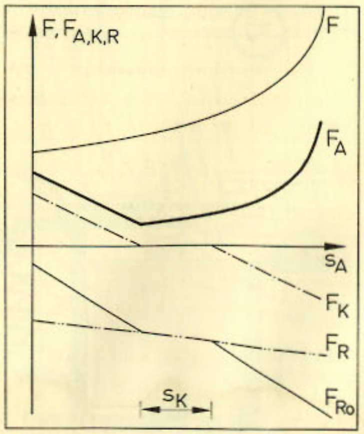


Fig. 9: Diagram of the electromagnetic pull-in force F, contact force F_K, reset spring force F_R and resulting armature holding force F_A against armature movement S_A. With the monostable relay shown in fig. 8, this movement when compared to the contact movement S_K is relatively high

returns the armature and the contact spring to a rest position. With polarized 2nd generation relays, armature resetting is much more elegantly implemented by use of permanent magnetic forces.
The interaction of the electromagnetic force of attraction F, contact force F_K, and reset spring force F_R in relation to the armature path s_A is illustrated in the force/movement diagram (fig. 9). The difference between the resultant reset spring force F_{RO} and attractive force F provides the armature setting force F_A.

Fifth part function

Conductance of Electrical Current via the Contacts

In the past, the erroneous view was widely held that during switching of very small loads, the mechanical life could be assumed to be the same as the life of the relay. Experience has shown that mechanical life exceeds electrical life for high load ranges by a factor of approximately 10^2. Due to the cessation of electrical stress, it was said, mechanical failures need only rarely be expected. Such an assertion was generally false, because gettering (see page 22) was not at that time in common use, and contact surfaces remained covered by foreign-body layers. The presence of these contaminants meant that below 0.1 V, high and inconstant contact resistances could occur (fig. 16). Electrical reliability was lost, resulting in considerable problems for many relay users.
Reliable contact operation depends on

- cleanliness of contacts,
- suitable contact materials and shape,
- high contact forces and low contact bounce.

Hence, the contact operation itself can be: poor (fig. 10, left); adequate (fig. 8); good (fig. 10, right) or optimal (figs. 11 and 12). Both the contact mass in fig. 8 and the force/

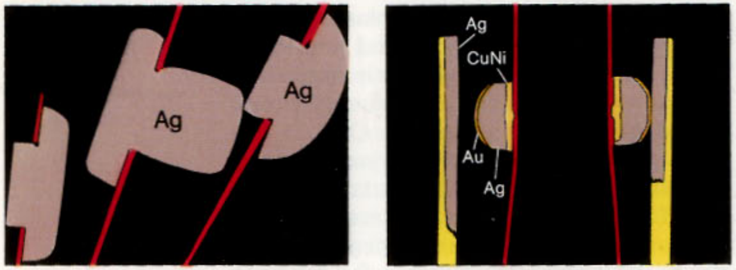


Fig. 10: Section through a conventional single-riveted-contact with point-shaped contact make (left) and a three layered welded contact with linear contact make. (K-relay from SDS [right], each magnified 15:1)

travel diagram (fig. 9) allow for ample wear reserves and lead to the expectation of long operational life. In contrast, the changeover contact shown in action in fig. 10, left, illustrates that with only little wear of the point-shaped contact, contact-make of the centre contact may be with the spring of the normally open contact, thereby limiting operational life.

The changeover contact arrangement of fig. 10, right, is that of a K-relay and is approximately 100 times more reliable than those illustrated on the left in fig. 10. With gold plated silver contacts (much less expenditure in precious metals), and its approximately 500 times greater load-break range of 10^{-6} to

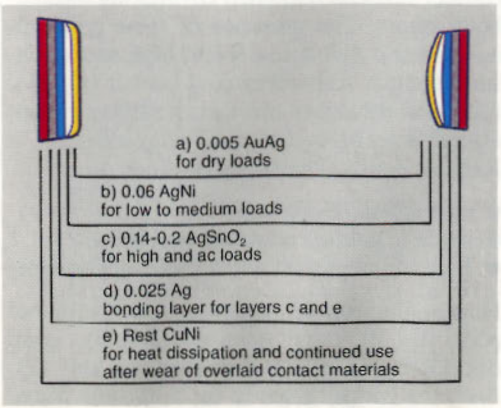


Fig. 11: Section through a 5-layered contact shown in fig. 12 and used in the S-relay (fig. 34). The numbers represent the layer thickness in mm

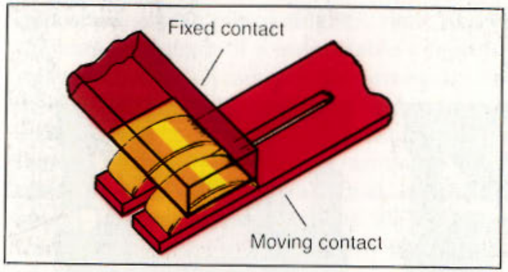


Fig. 12: Linear bifurcated contact increases contact reliability by a factor of approx. 50

120 VA, the application range of the K-relay contact is also greater.

A much more extended load-break range, namely from 10^{-10} to 1000 VA, is achieved by the 5-layer double linear contacts used in the S-relay (fig. 34, page 47), especially since, compared with point-shaped contacts:

Bifurcated linear contacts: major improvements in reliability

- uniformly thick gold plating is about five times more wear resistant;
- voltage and load are reliably switched even after 10^5 switching operations at 30 W, 2 A;
- contact resistance remains constant during a long operational life;
- short-circuit protection of 100 A is ensured for 1 ms.

These examples illustrate that even on the five basic part functions, which exist in all relays of the 1st generation, considerable improvements have been made.

2nd Generation Relays

Additional part functions

Modern 2nd generation relays have in addition one or more of the following part functions.

Sixth part function

Significant Superpositioning of Permanent Magnet and Electromagnetic Flux in the Air Gap

By inserting one or two permanent magnets into the magnetic circuit of the relay the direc-

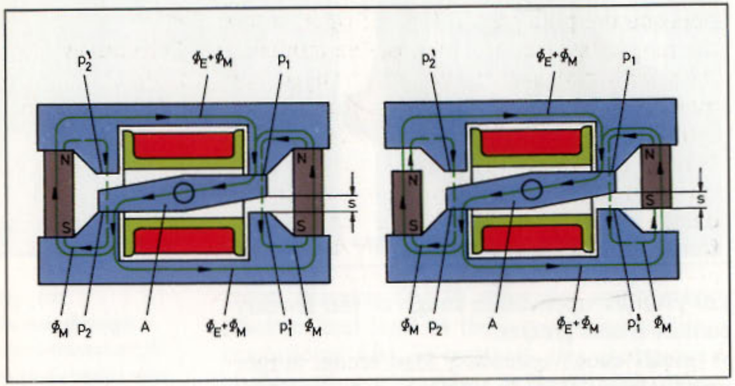


Fig. 13: Polarized magnet system of a bistable (left) and a monostable (right) miniature relay

tion of the contact force can be made dependent on the direction of the excitation current (polarized relay).

Fig. 13, left, shows a section through the polarized magnet system of a miniature relay with centre of gravity pivoted armature A, and permanent magnets. It will be seen that at the pole pieces P_1 and P_2, the excitation flux Φ_E generated by the coil, and the permanent magnet flux Φ_M superimpose to one total flux $\Phi_M + \Phi_E$, whereas there is only the permanent magnet flux Φ_M on pole pieces P_1' and P_2'. Due to the greater flux, the armature is attracted by pole pieces P_1 and P_2 and assumes the illustrated position.

If the coil current is reversed, there is a flux difference $\Phi_M - \Phi_E$ at the pole pieces P_1 and P_2, whereas the flux Φ_M remains at pole pieces P_1' and P_2'. Because the flux Φ_M is now greater than $\Phi_M - \Phi_E$, the armature is now moved from the stable position P_1P_2 into the stable position $P_1'P_2'$. A *monostable* relay differs from such a *bistable* (latching) relay by virtue of the fact that the opposing faces of the poles P_1P_1' and P_2P_2' are of different size and the permanent magnets are arranged assymmetrically (with single-sided air gap

Permanent magnet eliminates reset spring

opposite the pole piece). Fig. 13, right, shows the magnet system of a monostable miniature relay with two asymmetrically arranged permanent magnets, whereby the armature resetting – after the excitation has ceased – is retained, and the need for an armature reset spring is eliminated. In this case, much less energy is required to overcome the restoring force, because it is conditioned by the product of permanent and electromagnetic flux $\Phi_M \cdot \Phi_E$.

Polarized systems: higher contact forces

Fig. 14 shows the curve of the attraction force F of the armature in relation to the armature travel s for a polarized magnet system (e. g. fig. 13 right) and a non-polarized (e. g. fig. 7, page 11) magnet system of equal size, at 100 mW power consumption. Such a polarized system therefore produces a much higher attraction or contact force than a non-polarized system.

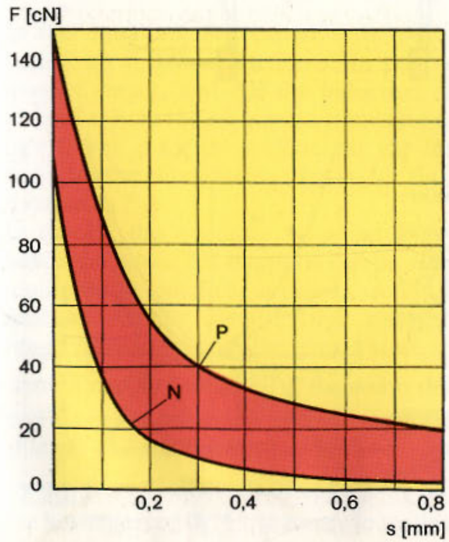


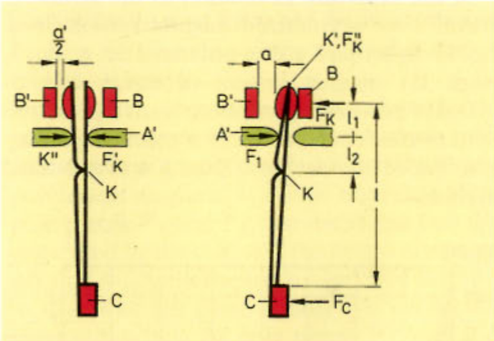
Fig. 14: Diagram of armature attraction force F in relation to armature movements s for a polarized (P) and an unpolarized (N) relay system. The curves illustrate that well-designed polarized systems consume significantly less power

Seventh part function

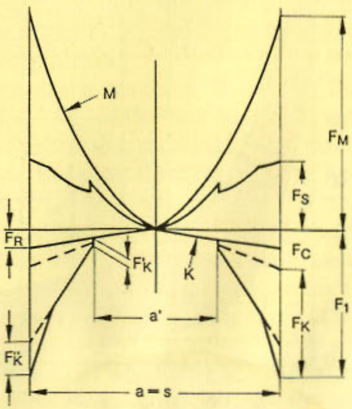
Storage of Magnetic Energy to Produce Contact Force

As recently as 1974, a technical journal rejected an article submitted for publication in which the author claimed that the excitation power – taking into account the stored energy of the permanent magnet – becomes less the larger the set contact forces. Designers of conventional relays have regarded such claims as suspiciously close to "perpetual motion", in particular, since it is considered that the production of higher contact forces requires correspondingly higher excitation power.

Fig. 15: Dual contact spring system FLOC (Flexure Lift Off Contact) in centre and end positions. Below the corresponding force/movement diagram of permanent magnet pull-in and holding forces as per fig. 13 (left)



- A' Armature (A) operating cam
- B, B' Fixed contacts
- C Moving contact mount
- F_C Force on moving contact mount
- F_K Contact force
- F'_K Spring pre-tension due to contact
- F''_K Additional contact force due to disturbance of the spring ends
- F_M Permanent magnetic pulling force
- F_R External force due to contact
- F_S Position force of armature $= F_M - F_1$
- F_1 $= F_K + F_C$
- a Contact gap
- a' Contact gap during operating
- l Contact spring length
- l_1 Spring length for contact operaton
- l_2 Additional spring leng for contact operation
- K, K', K'' Contact points of contact spring
- s Armature travel (fig. 9)



Selected from several patented methods of obtaining high contact force without excitation power, the FLOC (Flexure Lift Off Contact) method has proven to be the optimum.

The FLOC contact is illustrated in fig. 15, at both the centre and end positions. With this system, the contacts are opened by means of the armature actuating comb A′ with short spring length l_1 and contact-make is achieved by the larger spring length $l_1 + l_2$ with energy storing flexibility.

Properties of the Flexure Lift Off Contact

This results in

- a relatively large contact gap a (in fig. 15, below: a = s),
- lower contact bounce due to the touching points K, K′ and K″,
- significant reductions in power consumption and contact losses.

Contact pressure without power consumption

No power is consumed to achieve the high contact forces F_K, but only for the actuating force F_s:

$$F_s = \frac{A \cdot B}{\mu}\left(\frac{a \cdot B}{2d} - \Delta B\right) - F_1$$

In this equation, A represents the pole face surface area, B the induction of the permanent magnet circuit, and ΔB the induction of the excited coil, in the air gaps; a stands for armature travel, d for the residual air gap length, and μ for the permeability of iron (see fig. 15 in relation to F_1).

Eighth part function

In theory, the armature actuating force and hence the power consumption can be as low as required. In practice, however, relays must function reliably over a large temperature range. Consistent with the temperature coefficient of copper wire ($\frac{0.39\%}{K}$), the coil resistance and hence the minimum operating voltage will change, whereas ferrite magnets have negative temperature coefficients of approx $\frac{0.2\%}{K}$. From the lower part of fig. 15, it is easy to realize that

Temperature influence

a change due to temperature influence has a much larger effect on the actuating force F_s than on the attraction force F_M. By tuning the temperature coefficients of copper and permanent magnet, and the attraction and actuating forces, temperature influences can be compensated, so that the pick-up voltage remains almost constant.

Compensation of temperature influence

The most important factor in the FLOC system, however, is the *constancy of the low contact resistance* during a long operational life.

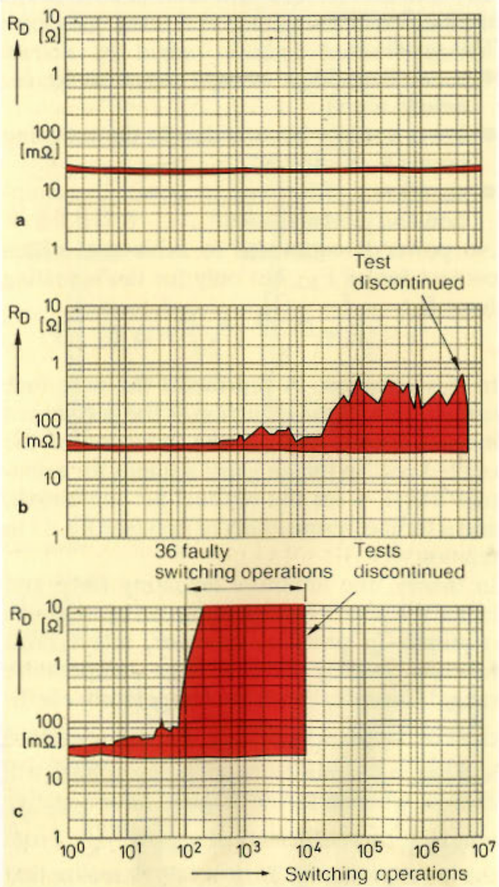


Fig. 16: Diagram of contact resistance of a FLOC relay (a), the next best relay (b) and the worst relay (c) from tests performed on 21 relays from various manufacturers, in proportion to the number of switching operations

Constancy of the low contact resistance

This phenomenon is illustrated by the test result of a relay user who checked the contact resistance in continuous operation at a load of 50 mV, 10 mA, and a switching frequency of 3 to 10 Hz on 21 different, externally almost identical, makes of competitive relays. Fig. 16 illustrates in orange the range of the measured contact resistance for 10 contacts of a FLOC relay (a), the next best (b), and the worst (c) system. The report concluded: "Out of 21 types from 16 manufacturers, only one type could be found which fulfilled the stated requirements. All the other relay types tested displayed volumetric resistances, which were between those of illustrations b and c (fig. 16)."

In addition to high contact forces and low bounce tendency of the FLOC relay, which are regarded as positive features, other types showed some of the following defects:

Causes of high contact resistance

- Unsuitable contact material (formation of oxide and sulphide layers due to a high content of non-precious metal or silver),
- formation of polymerization products with the use of palladium based alloys (together with degassing of plastics and missing gettering),
- unsuitable choice of material at friction locations (development of friction between actuating point and contact spring or in the armature bearing),
- poor assembly processes ("contaminations of the most careless nature in the relay interior").

It was also found that the fulfilment of the requirements for the use of relays in electronic measuring equipment – high though they may appear to some relay manufacturers – is not so much a question of cost, but of "know how".

This is substantiated by the one relay which meets these requirements. The FLOC relay is only marginally more expensive than the unsuitable competing devices.
If the line resistance of 18 mΩ is subtracted from the volumetric resistance illustrated, then the actual contact resistance at commencement of the test in the relay shown in fig. 16a was < 10 mΩ, in that of fig. 16b < 16 mΩ, and that of fig. 16c < 20 mΩ. This confirms earlier test conclusions that faulty switching tends to occur earlier in relays with proportionately higher contact resistance when new.

Ninth part function

Avoidance of Foreign Body Layer Build-Up on the Contacts by Means of a Special Gettering Method

A particular problem of relay technology, which for many years seemed insoluble, was that of foreign body layers or films forming on the relay contacts. These led to increased and unstable contact resistance. Such films can develop due to faulty manufacture or inadequate cleaning methods. They also form during use of the finished product. These films are formed mainly by the emission of vapours of aromatic hydrocarbons from the plastic parts of the relay. Due to high-energy charge carriers and UV energy which is emitted in relays during load switching, the hydrocarbon molecules are partly split into highly reactive molecules. These cross-link to form insulating plastics which desposit as a film on the contact surfaces thus increasing the resistance of the contact surface. In this process, the initially clean contact surfaces can even act as a catalyst and accelerate the cross-linking. Due to partial degradation and build-up of the film during switching actions, the contact resistance changes in an uncontrollable manner.

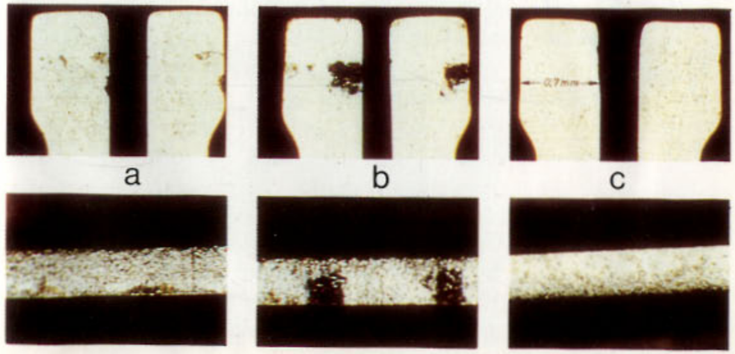
How films develop on contacts

But the formation of film on the contacts can be prevented. Foreign molecules, whose emission from plastic materials can never be fully prevented, are attracted and bound by so-called *getters*, which can be installed in the vicinity of contacts. A getter is a layer (for example, of an extremely pure, degassed metal), which adsorbs gas or vapour molecules in large quantities, i. e. binds them to its surface permanently. Such a getter however should selectively gather only organic foreign molecules. If it also adsorbs molecules from the atmosphere within the relay, this significantly reduces the internal pressure, and with it the dielectric strength. Because of this limitation, a number of well known getter materials cannot be considered for application within relays.

Help from getters

Unfortunately this applies to low-cost activated carbon, with its high adsorption rate for many types of molecules and its unsuitable average pore size (2 to 4 nm) compared to the average diameter of polymer molecules (> 100 nm). Major progress was achieved by the idea of activating the ferrite magnet (already present in the modern relay) to form a getter. To do this, the magnet surface of the open relay is cleared of foreign molecules at

Fig. 17: Surface condition of moving contacts (above) and fixed contacts (below) after heavy duty. On the gettered relay (c), the clean condition of the surfaces is seen to be substantially better



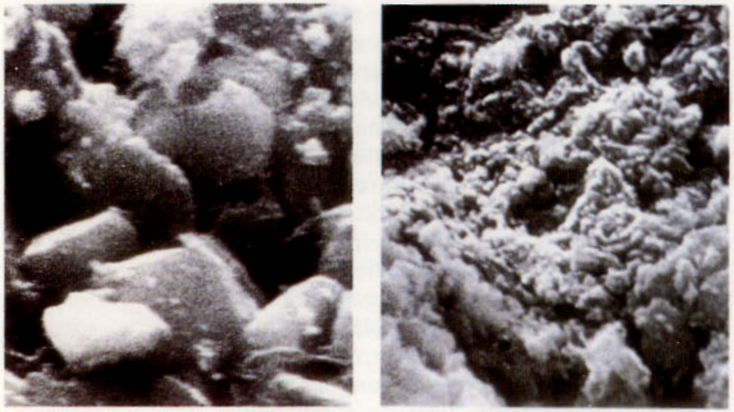


Fig. 18: Surface of a barium ferrite magnet activated to a getter (left) and an alumina additional getter (right) both magnified 26000 times

elevated temperature (130°C) and under high vacuum (approx. 10^{-8} bar). The relays are then sealed in a clean-air room at normal pressure and a relative air humidity of 15%.

After brief adsorption of various gas molecules present in the relay interior, the required selective and long lasting binding of organic foreign molecules takes place. By adding an additional getter, e. g. from alumina, the getter effect can be intensified.

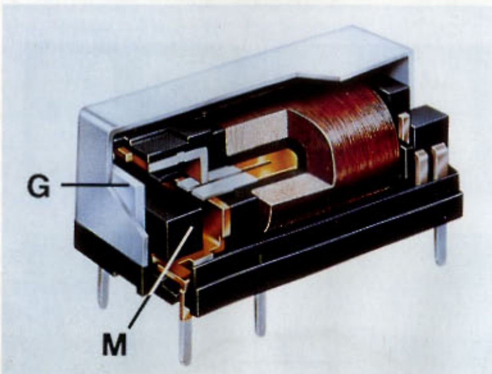


Fig. 19: Relay with ferrite magnet getter M and additional getter G. (DR-type from SDS)

Fig. 20: Manufacture and quality control of modern relays is done under exceptionally clean conditions

The introduction of the new getter method in 1975 brought about a significant reduction in the number of rejections from almost 0.5% to 0.004% (see also fig. 48, page 63). This reduction offers major savings in view of the high costs usually involved in rectifying reject parts. During long term investigations, gettered relays have proved their much enhanced quality compared to that of ungettered relays, by virtue of

What do getters achieve?

- contact resistance lower, by approximately 30% on average (with a standard deviation reduced by about 50%),
- an approximately 40 times higher number of switching operations until the first occurrence of a faulty switching cycle (load: 150 mV, 15 mA, 100 Hz),
- a 100 times greater contact reliability.

These developments of 2nd generation relays provided the basis for a significant symbiosis of modern relay technology with electronic components, to develop *IC relays*.

3rd Generation Relays

Relays and electronics

Relays of the 3rd generation represent a marriage of 2nd generation relays with modern electronics, so that energy, space, and cost savings can be made, while various different switching functions can be achieved or programmed.

Tenth part function

Limiting Power Consumption to the Pick-Up Time of the Relay

By combining a polarized miniature relay with a simple semiconductor circuit, it has become possible to utilize the advantages of bistable relays in monostable switching applications. Such behaviour is achieved by the *C-switching circuit*. In addition to several diodes and transistors, it contains a capacitor which is connected in series with the coil of the bistable relay.

Action of the C-switching circuit

To drive this relay, input 1 can be used for various voltages. Input 2 can optionally be driven with voltages which are predetermined by the threshold voltage of the Zener diode. If voltage is applied between 1 and 3 or 2 and 3, then a charging current, i, will flow through the relay coil.

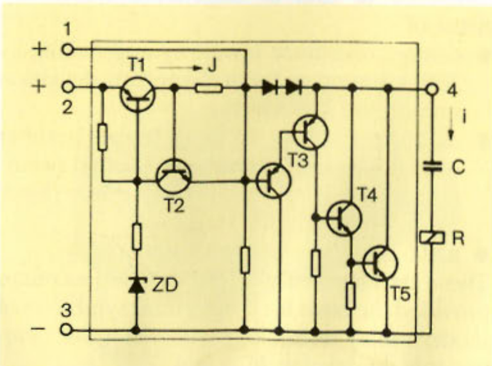


Fig. 21: C-switching circuit to limit power consumption to the pick-up time of the relay

Monostable switching almost without power consumption

This causes the relay to pick-up, and the capacitor to charge. The charging time constant of the capacitor C, and the relay's coil resistance, is selected so as to be similar to the relay pick-up time (typically a few ms).
Thus, so long as voltage is applied, power consumption is limited to the pick-up time of the relay. With the exception of unavoidable leakage current, of typically 100 μA, no more current flows, and hence there is no more power consumed.

Eleventh part function

Storage of Electrical Energy to Achieve Contact Opening after Removal of Excitation Voltage

If the relay described above were monostable, it would drop out immediately after the coil current had decayed. A bistable polarized relay, however, remains in the last switched condition, until it receives a pulse of opposite polarity. This occurs when the exciting voltage E drops below the response value of the trigger stage. The capacitor then discharges via the transistors T4 and T5, and a current, –i, now flows through the relay coil. The bistable relay sees this as a change of polarity of the excitation voltage, and reacts by switching-back into

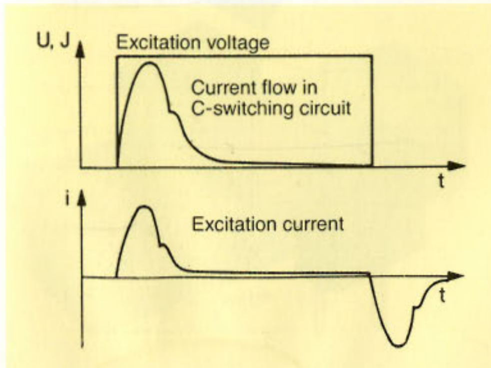


Fig. 22: Excitation current and voltage of a relay with C-switching circuit

the contact rest position. Since the energy required for this operation is stored in the capacitor, no further power is consumed from the power source.
Fig. 23 shows how the capacitor and the integrated circuit (IC) are mounted within an R-relay.
The significance of the C-switching circuit is that monostable switching characteristics are achieved with extremely low power consumption. Depending on the duty cycle or the switching frequency, it is possible to achieve power savings of up to 99.9% of the energy required when compared with equivalent conventional monostable relays. The benefits are low self-heating and hence minimal heat stress for the relay and for adjacent components. This permits high packing density and leads to very low thermo-electromotive forces of less than 1 μV at the contacts.

Up to 99.9% power savings

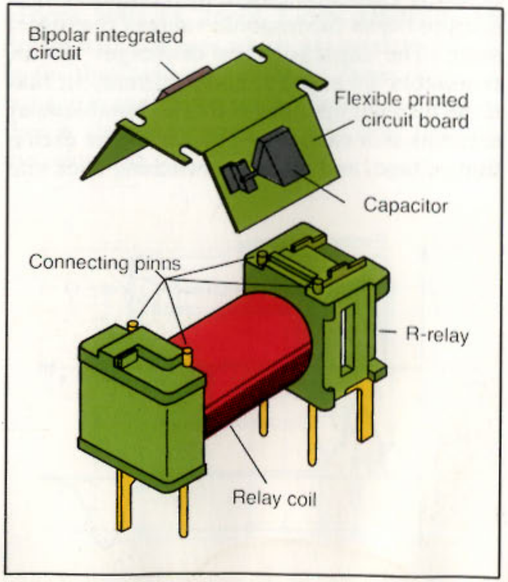


Fig. 23: Arrangement of the C-switching circuit in an R-relay. The C-switching circuit can also be built into a plug-in socket (fig. 35) or, for the most cost-effective solution, can be mounted directly onto the pcb and connected with the relay

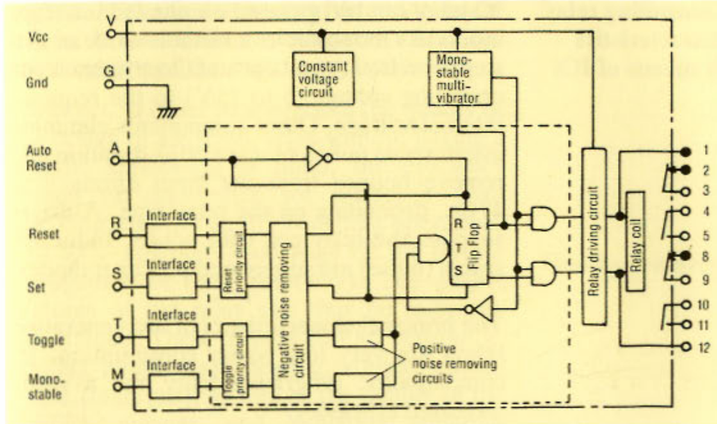


Fig. 24: Block diagram of an electronically controlled IC relay

Combination of Several Programmable Functions

The symbiosis of integrated circuits with relays in the shape of IC-relays has helped expand potential applications of relay technology considerably. Fig. 24 shows the electronic control block diagram of an IC-relay. Equipped with an input interface, the relay is LSI compatible. It can be combined with TTL, CMOS, PROM or microprocessor modules, or connected to a control bus. Using a special control circuit, the

Twelfth part function

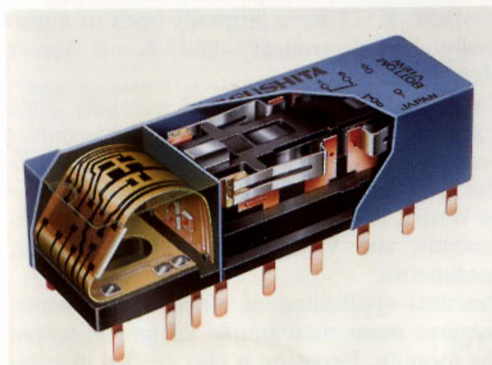


Fig. 25: Construction of an IC-relay

Controlling relay characteristics by means of ICs

IC-relay can be operated on parallel interface inputs in a monostable or bistable mode or as a stepper relay. A voltage stabilizer reduces the operating voltage (5 to 15 V) to the required internal voltage. Other components eliminate interference pulses of up to 50 µs duration and remove bounce from the input during 8 to 47 ms, depending on the relay type. A driver supplies the relay coil with power. Induction spikes (noise) are suppressed by Zener diodes.

The principal characteristics of 3rd generation relays are very low power consumption, IC compatibility, programmability and a vastly increased efficiency.

Efficiency of Relays

The efficiency ηL, related to a given operational life, is a principal quality feature of electromagnetic relays, and is calculated from

Determining efficiency

$$\eta_L = \frac{K \cdot P}{E \cdot V}$$

In the formula, K represents the number of contacts. K = 1 for a normally open or a normally closed contact, and K = 2 for a changeover contact.
Example: Value of K for 2 normally open contacts, 1 normally closed and 2 changeover contacts $= 2 \cdot 1 + 1 \cdot 1 + 2 \cdot 2 = 7$. P represents the load switching capacity in Volt-Ampères or Watts), E is the power consumption in watt-seconds, and V the relay volume in cubic centimetres.
Practical application of efficiency, however, requires more than simple arithmetic within the formula. Expertise is also needed in relating it to a specified operating life and to establishing if the number of contacts meets the requirements of the specific application.

Quality features

However, in order to appreciate the quality of the design of any given relay without having a specific application in mind, the efficiency should be established for maximum load breaking capacity at 10^5 switching operations and 95% reliability (see page 62 for further explanation of relay *reliability*). The quality features of the relay can thus be indirectly ascertained. These include contact resistance, contact bounce, self-heating, contact atmosphere (inert gas), as well as the quality of the contact, magnet, and insulating materials used. In optimum conditions, the efficiency can be directly related to the number of part functions which it encompasses. Comparisons of relay efficiencies presume similarity. It should be borne in mind that the efficiency of electronic or photoelectric relays (see page 36) is largely independent of operational life.

Generally, the efficiency of the three different relay generations, taking into account monostable switching behaviour at 10^5 switching operations, can be approximated as shown in the table below.

Table 2: Typical efficiency values ηL of the three relay generations at 10^5 switching operations

Relay generation		1	2	3
Part functions as described		1 – 5	1 – 9	1 – 12
Reed changeover relay	η_L	20	500	10^5
Pcb relay (4 contacts)	η_L	200	5000	10^6
Time delay relay	η_L	10	200	10^3

It may be appropriate in future to allocate an "intelligence quotient", which is yet to be defined, to the efficiency of 3rd generation programmable relays, some of which will soon be available with inbuilt integrated microprocessors.

Efficiency in the past

The concept of efficiency reflects the history of the relay. Until 1968, before the development of 2nd generation relays, efficiency was simply the relationship of load-switching capability to power consumption. Such relay types with large, long coils, are illustrated in fig. 2.

20 Years of "Relay Evolution" – The Results to Date

Miniaturization with higher performance and reliability

The optimization of part functions within conventional relay technology and the addition of a further four part functions, cybernetically tuned one to another, has brought about drastic miniaturization, while simultaneously increasing relay performance and reliability. This optimization characterizes the 2nd relay generation. Thus, as early as 1980, the foundations were laid for a symbiosis of modern relays with modern electronics. With the addition of further part functions, the 3rd relay generation was developed. Now, in a multiplicity of different versions, these operate with the highest efficiency at the nerve centres of technology.

The following summarizes the fundamental improvements brought about by the various relay developments to date:

What has been achieved?

- up to 99.9% power saving
- 10 times longer operational life
- 100 times higher contact reliability
- 1000 times greater efficiency

Fig. 26: Computer-aided analysis of relay characteristics in development laboratory

- 10,000 times greater load-switching range
- reduced volume and transportation costs
- lower switching noise
- low heat development
- less stress on adjacent components
- negligible operating costs

There is as yet no end in sight to the development of the electromagnetic relay. On the contrary, IC-relays of the 3rd generation are being developed further. Surprisingly, the electromagnetic relay, which was once pronounced dead, is very much alive and kicking, and it has taken its rightful place within modern electronic technology.

Other Relay Principles

Electronic switching

From a multitude of different relay designs, certain solid state relays have become economically and technically important.

Solid State Relays

Several semiconductor devices such as triacs, thyristors, and power transistors can be used in a similar way to electromagnetic relays, to switch DC or AC circuits, by applying low level control pulses. Fig. 27 shows the schematic diagrams and load-switching characteristics of a triac and a MOS power transistor. By

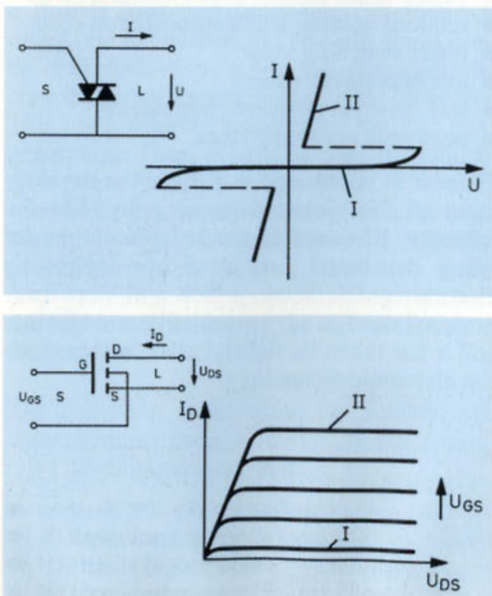


Fig. 27: Schematic and voltage-current relationships of a triac (above) and a MOS power transistor (below) used as solid state relays (U = switched voltage; I = switched current; G = gate; S = source; D = drain)

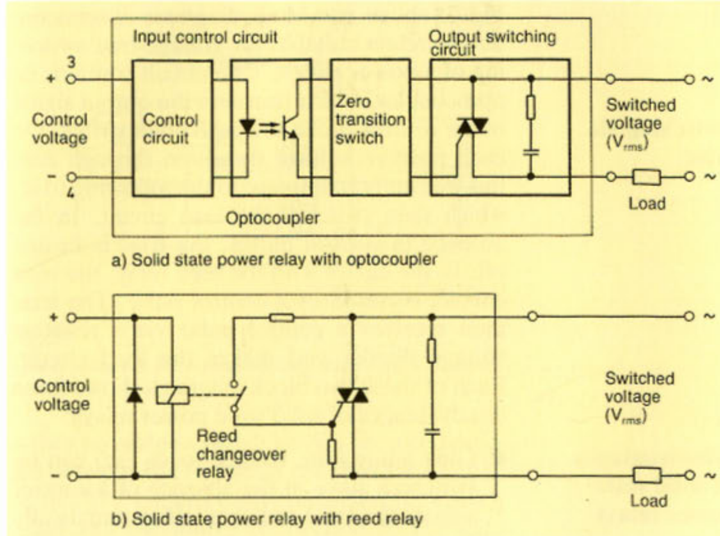


Fig. 28: Block diagram of different types of electronic power relays (solid state relays)

applying a voltage pulse to the control circuit S, the particular element switches from the OFF to the ON condition, thereby switching the load circuit L. In the load-switching diagrams, the characteristic curve I represents the OFF condition, and curve II defines the ON condition of each device.

Structure of Semiconductor Relays

Isolation by means of optocoupler or reed relay

Since none of these semiconductor switch elements offers galvanic separation between control and load circuits, a suitable separation element is needed (e. g. optocoupler or reed relay). By combining such a semiconductor device with an appropriate control circuit an electronic solid state relay can be developed.

Fig. 28 shows two block diagrams of semiconductor relays suitable for voltage-free switching of a power circuit. One circuit contains an optocoupler, which transfers the output signal of the control circuit to a zero point switch. On each positive voltage transition through zero this transmits an impulse to the following triac, which then switches the load circuit. In the absence of control pulses, the triac is turned off. In the circuit with the reed relay, the reed contact is closed by a control pulse. The triac then receives a control pulse via a resistive voltage divider and makes the load circuit. Each of these two block diagrams shows three disadvantages of solid state power relays:

Switching via triac

Disadvantages of solid state power relays

- Only alternating voltage loads (ac) can be switched, since in the absence of a control signal, the triac switches off automatically at zero voltage transition.
- Since the isolation element can only transmit the control signal and no load, the power required for switching must come from the load, making it difficult to switch very low load levels.
- To avoid self-firing during rapid voltage rise in the load circuit, an RC network must be inserted. This can conduct alternating current. In the OFF state there is a residual current of about 1 mA at 240 V/50 Hz.

Photoelectric Relays

The disadvantages of the semiconductor relays mentioned are avoided by the photoelectric relay shown in fig. 29. In the photo-MOS relay the light from an LED in the input circuit produces a voltage in a solar cell which then drives the gate of a bidirectional MOS-FET. It

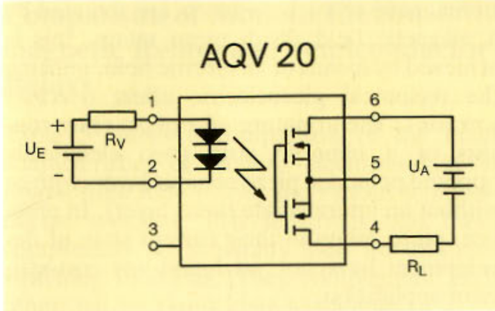


Fig. 29:
Circuit diagram for a photovoltaic relay (AQV20 type from SDS)

is thus possible to switch an AC circuit connected between the two drain connections 4 and 6, or two DC circuits each connected between a drain and the source connection 5. The gate voltage produced by the solar cell is completely independent of the switched load voltage. The advantages of the photo-MOS relay may be summarized as follows:

Advantages of the photoelectric relay

- It can switch both dc and ac loads.
- Its switching range extends from the microvolt/nano-ampère range up to 400 V at 0.15 VA.
- It has a stable, constant volumetric resistance throughout its entire life.
- The leakage current is $< 1\,\mu A$.
- It shows no self-firing during rapid rise of the load voltage.

Further data of a photo-MOS relay of the SDS type AQV 20 is on pages 40/41 in table 3.

Piezo Relays

In view of the abundant patent literature, the piezo relay should be mentioned. In the elec-

Piezo Relays

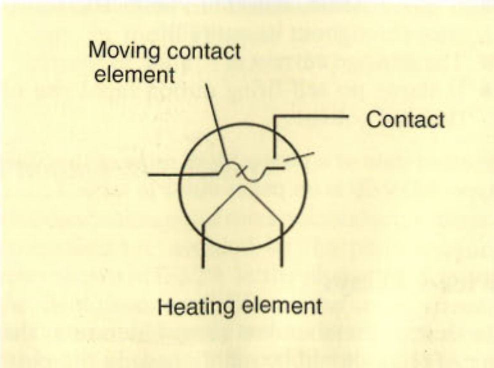
tromagnetic relay the contacts are actuated by a magnetic field. With piezo relays, this is achieved by means of an electric field, utilizing the reciprocal piezoelectric effect *(electric-striction)*. The armature of a piezo relay consists of a bimorph strip (two electrically opposed polarized piezo ceramic layers with or without an intermediate metal layer). In practice, piezo relays in their current state of development have not yet found any cost-efficient application.

Thermo-Electric Relays

Thermo-electric relays are used in very limited, restricted ranges of applications. In this type of relay, the heat produced by a current-carrying conductor is used to make or break a contact. The flexible contact finger consists of a bimetalic strip, which bends due to the heating effect of the heating element and thereby actuates the contact. Time delays of 0.1 to 300 seconds are achievable.

Core piece: bimetal strip

Fig. 30:
Construction of a thermo relay



Comparison of Modern Electromagnetic Relays and Semiconductor Relays

Table 3 shows a comparison of the main characteristics of modern electromechanical relays, solid state relays, and various semiconductor switches. This illustrates that these components are generally used for different switching functions. They complement each other, but are rarely interchangeable.

Contact arrangement

Due to their *contact arrangement*, electromechanical relays (EMR) can switch several circuits, whereas a solid state relay or semiconductor switch can switch only one. Exceptions are CMOS switches. With semiconductor switches the *volumetric resistance* is defined as the relation of forward voltage drop to forward current. The *insulation resistance* of relays is a measure both of the electrical isolation of input and output circuits and of the isolation of open contacts. It is several times higher than the corresponding barrier layer resistance of semi-conductor switches which have no electrical separation between input and output. Such separation exists only in photoelectric relays and optocouplers.

Resistances at the contact

Contact Capacitance

Contact capacitance is an indicator of the suitability of a relay for use at high frequency, and is usually measured in pico-Farad (pF). Distinction is made between capacitance between: open contacts; contact pairs one to another; and between contact and earth. The values stated in table 3 are for open contacts (coil or housing earthed). On semiconductor switches contact capacitance corresponds to the no-load barrier layer capacitance, which is voltage dependent and can amount to between 5 and 400 pF.

	Modern relays									Modern solid state relays						
Construction																
Type m monostable, b bistable (latching)	DR m	DRL b	DRC m	S m	SL b	DS2 m	DSP m	TQ2 m	TQ2-L b	TIL 126 Optocoupler m	AQV 204 PhotoMOS-Relay m	BD 241 C Transistor m	TIC 106 M Thyristor	TIC 206 M Triac	BUZ 71 MOSFET m	MC14066 Analog switch CMOS m
Contact type (NO–Normally Open NC–Normally Closed CO–Changeover)	1 CO		1 CO	2NO2NC 4NO 3NO1NC		2CO	1NO1NC	2CO		1NO	1NO[2NO]	1NO	1NO	1NO	1NO	4NO(3NO)
Volumetric/contact resistance mΩ	30/10		30/10	30/10		35/10	15/10	50/20		10^4	4000	400	340	520	100	2.8×10^5
Insulation resistance Ω	10^{10}		10^{10}	10^{10}		10^{10}	10^9	10^9		2×10^6	4×10^8	5×10^5	1.5×10^6	5×10^5	2×10^6	1.5×10^7
Contact capacitance, coil or screen earthed pF	0.3		0.3	0.5		0.8	0.4	0.8		–	100	–	–	–	400	–
Volume[6] (with heat sink) cm^3/contact	0.84		0.84	0.84		0.46	1.11	0.16		0.25	0.22 [0.11]	0.8 (13)	0.8 (13)	0.8 (13)	0.8 (13)	0.2
Switched current range A	$10^{-6}...3$		$10^{-6}...3$	$10^{-7}...5$		$10^{-5}...3$	$10^{-3}...5$	$10^{-6}...1$		$10^{-5}...0.04$	0...0.2 [0.1]	$10^{-2}...5$	0.008 ... 5(30[7])	0.03...4 (30[7])	0 ... 36	$10^{-5}...0.025$
Switched voltage range V	$10^{-5}...250$		$10^{-5}...250$	$10^{-5}...250$		$10^{-5}...250$	0.1...380	$10^{-3}...125$		1 ... 30 =	0 ... 400	1 ... 100 =	1 ... 600 ~	1 ... 220 ~	0 ... 50 =	0 ... 18 =
Switched load range W/VA	$10^{-9}...30/60$		$10^{-9}...30/60$	$10^{-10}...100/1000$		10^{-9}-90/250	1...150/1200	$10^{-5}...60/100$		–	0 ... 80/40	$10^{-2}...300/–$	–/0.008...1100	–/0.03...880	0 ... 600/–	0 ... 0.4/–
Max. continuous current A	3		3	5		4	5	2		0.01	0.2 [0.1]	3	5	4	12	0.025
Pick-up time + bounce time ms	1 + 0.4		0.5 + 0.4	8 + 1		3 + 1	5 + 2	2 + 1		0.002 + 0	1 + 0	0.0003 + 0	0.004 + 0	–	$10^{-4} + 0$	0.0001 + 0
Pick-up power consumption at 20°C and max continuous current mW	60	40	336[3]	97	48	98	200	80	56	12	120	300	1[2]	11	4×10^{-4}	0.01
Power consumption at max continuous current mW	100	0[2]	0.04	200	0[2]	200	300	140	0[2]	60	120	2000	3000	4500	4×10^{-4}	150
Permissible deviation from nominal voltage %	+150 –20		+100 –20	+100 –30		+100 –25		+85 –30		–	+400	–	–	–	+400	–
Electrical life[4] No. of ops.	10^8		10^8	2×10^8		10^8	5×10^7	10^8		∞	∞	∞	∞	∞	∞	∞
Permissible ambient temperature at 100% duty cycle °C	–55 +85		–55 +75	–55 +65		–50 +80		–55 +72		0 +100	–20 +80	–65 +150	–40 +110	–40 +110	–55 +150	–40 +85
Shock & Vibration resistance g-g/Hz	100-20/2k		100-20/2k	50-20/1k		50-20/1k	20-12/55	50 – 20/10...55		–	50-20/10...2000	–	–	–	–	–
Standard voltages (current) V(mA)	1.5 – 24		5 – 12	1.5 – 48		1.5 – 48	3 – 48	3 – 24		(40)	3(10)	1.0	0.7 (10)	1.2 (10)	4 (10^{-7})	3 – 15 (→0)
Cost per contact (for 100 devices)[6] £	1.00	1.05	1.80	0.75	0.80	0.60	0.90	0.50		0.70	4.25[2.10]	0.25	0.40	0.42	1.00	0.07

Table 3: Comparison of characteristics of modern electro-mechanical relays, solid state relays and solid state switches

advantage

disadvantage

Switching ranges

The *switched current range* of relays depends, among other factors, on the contact force and on the type, cleanliness, and geometry of the contacts. With semi-conductor devices it is mainly determined by the chip size and the thermal resistance. The *switched voltage range* of relays is determined for closed contacts by the size of the contact resistance (minimum voltage), and with open contacts by the contact gap (maximum voltage). For semi-conductor switches it is limited by both the saturation voltage and by the maximum collector/emitter blocking voltage. With electro-mechanical relays the *switched load range* can extend over a range of 10^{13}. With semi-conductor switches it is determined by the SOA (Safe Operating Area) and thus is limited to a range of 10^5.

Pull-in power consumption

The *pull-in power consumption* for EMR is that consumed by the coil which results in the relay just operating. In semi-conductor switches it is the product of input voltage U_{BE} and the input current I_B, which will just effect saturation. I_B is dependent on the switching current I_S.

The *power consumption* in EMRs is higher than the pull-in power by a safety factor that takes into account wear phenomena, environmental influences, and manufacturing tolerances. In solid state switches it is equal to the pull-in power plus a safety margin, plus collector dissipation.

1) For semiconductors the max switched voltage applies
2) When controlled via impulses
3) Limited to 1 ms then 0.04
4) With suitable switched load
5) For semiconductors the max component temperature applies
6) 1 changeover ≙ 2 contacts
7) Only one half wave 50 Hz

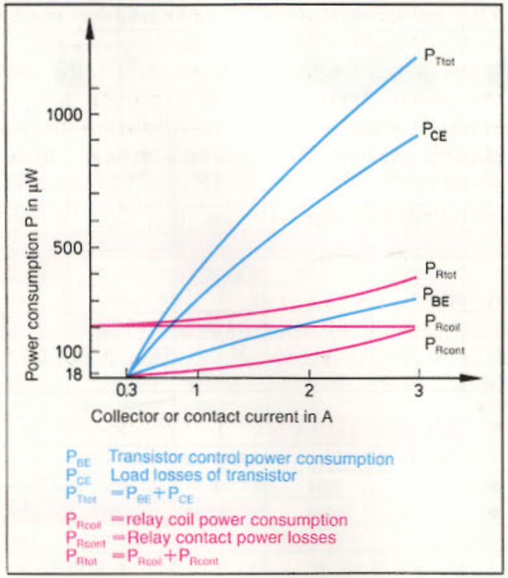


Fig. 31: Examples of power consumption of transistor BD241C (blue) compared with S-type relay from SDS (red) in proportion to collector or contact current

Fig. 31 shows that the power consumption of solid state devices rises much more steeply in relation to the collector current (example: transistor BD 241 C) than it does with electro-mechanical relays in relation to contact current (example: S relay).

Bounce time

The *maximum bounce time* of an electro-mechanical relay is the period from the first to the last closing or opening of a relay contact during the changeover into another switching position. Bouncing causes short-term contact interruptions. These do not occur in semi-conductor devices.

Life

The *maximum electrical life* of an electro-mechanical relay is the maximum permissible number of switch operations at a specified contact load under specified conditions, with an operating reliability of 95%. In semi-conductor devices it is unlimited.

Temperatures

The *permissible ambient temperature* of an electro-mechanical relay is the difference between the temperature which results from coil and contact heating, and the upper limit temperature, which is determined by the type of plastics used in the relay. In semi-conductor switches it corresponds to the permissible barrier-layer temperature.

Application Criteria of Electro-mechanical Relays and Semi-conductor Switches

Electro-mechanical relays

Electro-mechanical relays are more suitable for use in the following circumstances:

- with overloads where no elaborate protection measures are needed;
- for extensive immunity to electrical faults;
- for switching independently of the current direction (dc and ac up into the GHz range);
- with low switching losses;
- when electrical isolation between all contacts and between contacts and the coil is needed.

Semiconductor switches

Semi-conductor switches are particularly suitable when the emphasis is on

- switching times < 0.2 ms,
- freedom from bounce,
- life being independent of the number of switching operations,
- loss-free switching during zero transition of load current,
- immunity to shocks and vibration.

Types of Relay

Reed Change-Over Relay

It is worth making comparison of the three generations of relays which have now been developed.

First relay of the second generation

Fig. 32 shows as an example a traditional reed change-over relay having five part functions and a modern relay having eight part functions. Lower costs coupled with higher efficiency and smaller volume contradict the conventional views on relay.

The reed change-over relay developed by the Bell Laboratories in the fifties (fig. 32 left) contains a sealed glass tube, into which one non-magnetic (2) and two ferromagnetic reeds (1, 1′) have been sealed. On energization of the coil, contacts 1 and 1′ will close.

One disadvantage is that silicate vapours are released during the sealing of the glass. They precipitate onto the reeds 1 and 1′ and thereby cause a high and irregular contact resistance. Furthermore, the contact force is

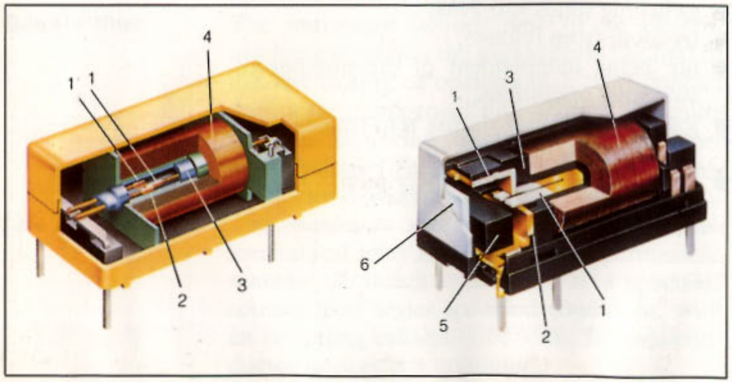


Fig. 32: Conventional reed changeover relay with five part functions (left) and modern reed changeover relay (right) with eight part functions

relatively low, making such relays suitable for only a small range of load switching. Thermal and mechanical stresses on the metal/glass touching points can lead to hairline cracks, through which pollutant gases can penetrate over a period of time thereby degrading switching characteristics.

Problems of conventional reed relays

With little extra cost, however, an improvement in quality, as illustrated in table 4, can be achieved. This requires that several part functions of the 1st and 2nd relay generations are optimized, sensibly combined and tuned, one to another, by

- mounting the coil carrier in a space and cost-saving manner along with fixed contacts (1′ and 2) and configuring it as the protective envelope;
- arranging a magnet (5) so that its flux overlaps with the flux of the excitation coil;
- tuning the temperature coefficient of the magnet to that of the excitation coil (temperature compensation);
- activating the magnet as a getter;
- undertaking the adjustment in the relay's own magnetic field;

Table 4: Power/price comparison of a conventional reed changeover relay (a) with modern 2nd and 3rd generation relays (b) shows major improvements as well as lower manufacturing costs inspite of miniaturization

Reed changeover relay as shown in fig 32	a left	b right		Improvement factor	
Relay generation	1	2	3	2	3
Component volume cm^3	3.2	1.7		1.9	
Power consumption mWs	150	100	0.2	1.5	750
Contact force cN	Approx. 2	10		Approx. 5	
Contact resistance mΩ	130	10		13	
Load switching range VA	10^{-6}...2.8	10^{-10}... 60		210000	
Change in pick-up voltage %/K	0.4	0.1	0.02	4	20
Efficiency (at 10^5 sw.ops)	12	720	10^5	60	8000
Price each for 1000 pcs £	4.50	1.70	3.20	2.60	1.40

How the reed relay has been optimized

- splitting the reed (1), in order to obtain a more reliable double (bifurcated) contact;
- filling the relay with inert gas and encapsulating in resin.

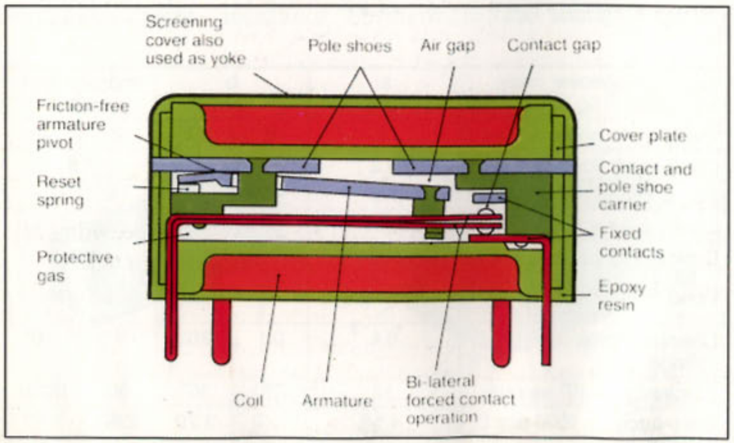
The result of these measures is a drastic reduction in the average number of complaints (see fig. 48).

Non-Polarized Relays

Fig. 33 shows a modern, non-polarized relay with twin forced-operated contacts. An innovation of this relay type is that the armature airgap is in the coil centre, whereby leakage flux losses are avoided, whilst simultaneously the interior of the coil body serves as an inert-gas-filled contact chamber.

If more than one change-over contact is provided in a relay, it must be ensured that the contacts open and close synchronously; as a rule, all contacts should be open for a minimum period (50 µs).

Fig. 33: Construction of a modern unpolarized relay with armature and contacts arranged at coil centre



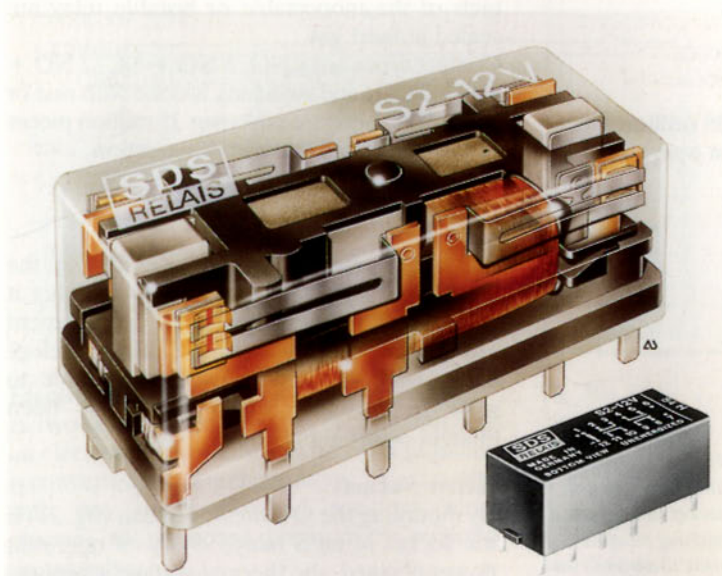


Fig. 34: Example of a universal polarized relay of highest efficiency and quality. SDS type S shown full size (right)

Polarized Relays

To complement the schematic diagram shown in fig. 13, the actual construction of a modern polarized relay (type S from SDS) is shown in fig. 34. Permanent flux and excitation flux overlap in the airgaps between armature and pole shoes. The contact force is obtained mainly from the stored permanent magnetic pull-in force. This provides high contact forces for only low power consumption. The four twin bifurcated contacts can also be seen (see figs. 11 and 12). These characteristics result in the S relay being able to switch an extraordinarily large load range from 10^{-10} to 10^{3} VA. For the S relay type, fig. 47 (page 62) and table 3 (pages 40 and 41) illustrate the operational characteristics which no other relay type can achieve and yet still offer an electrical life of up to $2 \cdot 10^{8}$ switching operations. The four con-

The meaning of "universal"

tacts of the monostable or bistable relay are sealed in inert gas.
Contact types are 4 NO, 3 NO + NC, 2 NO + 2 NC (2 CO) and switching is done with one or two coils. There are now over 35 million pieces of this "universal" device in operation.

35 million pieces in operation

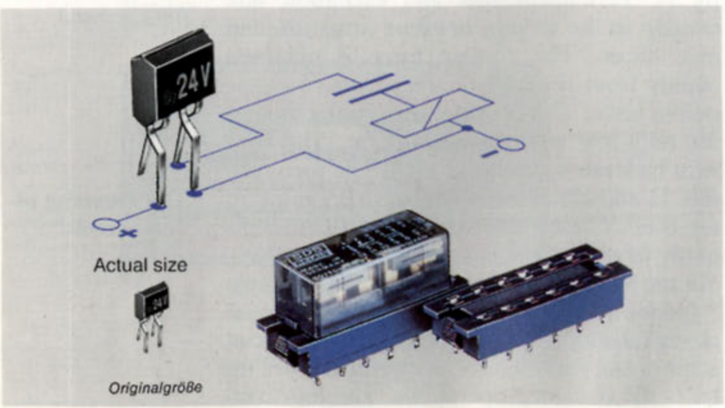
IC Relays

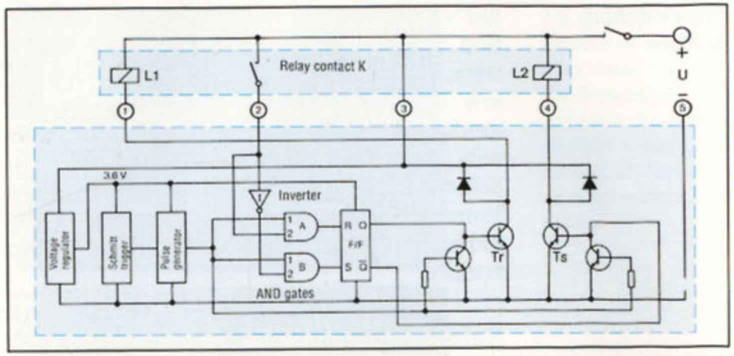
The achievements made in developing the S relay are by no means over. Combining it with IC technology has led to the development of a 3rd generation of relays. These developments have resulted in users being able to solve applications which have not been thought possible previously.

Active Socket

By mounting the C-switching circuit (fig. 21) in the socket of an S relay, 99.9% of operating power is saved, the thermal voltage is reduced to 1 μV even at 100% duty cycle. The pull-in time is halved. This first "active" socket converts a bistable S relay into a monostable relay without power consumption in the operated condition, and a monostable relay into a wiper (impulse) relay.

Fig. 35: First active plug-in socket. It converts a latching relay (S-relay illustrated) into a monostable relay that consumes no power in the operated state or converts a monostable relay into an impulse relay.



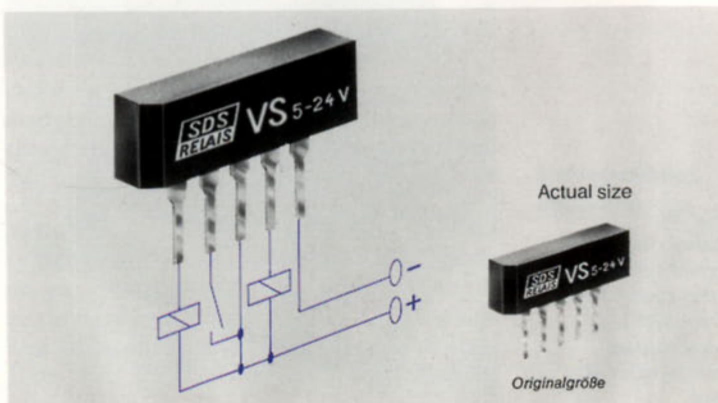


Electronically Controlled Stepper Relays

A two-coil bistable relay, in conjunction with an electronic pre-selector switch (VS module), is converted into a stepper relay. This is a relay with two stable switched positions which changes the switched position by unidirectional pulses.
The VS module circuit diagram shows that after an impulse either relay coil L 1 or L 2 will be excited, depending on the position of the relay contact K. After the switching action, contact K will be in the opposite switching position. The contact K has no influence on

Fig. 36: Switching diagram of the VS-module from SDS

Fig. 37: VS-module to convert a two coil bistable (latching) relay into a stepper relay



Pre-switching module

the VS module. Due to the action of the flip-flop F/F, the relay remains in the attained state, until the operating voltage U drops below 2V. Functional units built into the VS module include a voltage regulator, which permits operation between 3.5 and 28 V, a Schmitt trigger threshold switch, and a pulse generator, which ensures a safe function of the module, even with signals which have severe bounce.

Safety Relays

Safety relays must switch machines and systems which have to comply with special safety requirements (e. g. presses, furnaces, railway signalling equipment, medical apparatus etc.) in an "inherently safe" manner. This requires at least two series-connected, independently operated contacts, which are usually the normally open contacts of monostable relays.

Basic requirement: circuit must open in spite of welding

If one of the contacts welds, then the second contact in the series performs the switch-off of the circuit. Fault recognition is undertaken by a forced-operated normally closed contact, which is operated simultaneously with the nor-

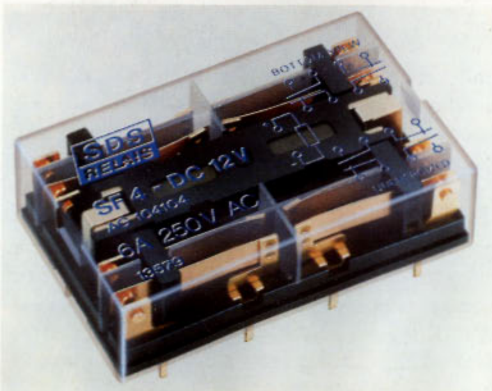


Fig. 38:
Safety relay shown actual size. The SF relay (Safety First) from SDS is the most modern development of its type.

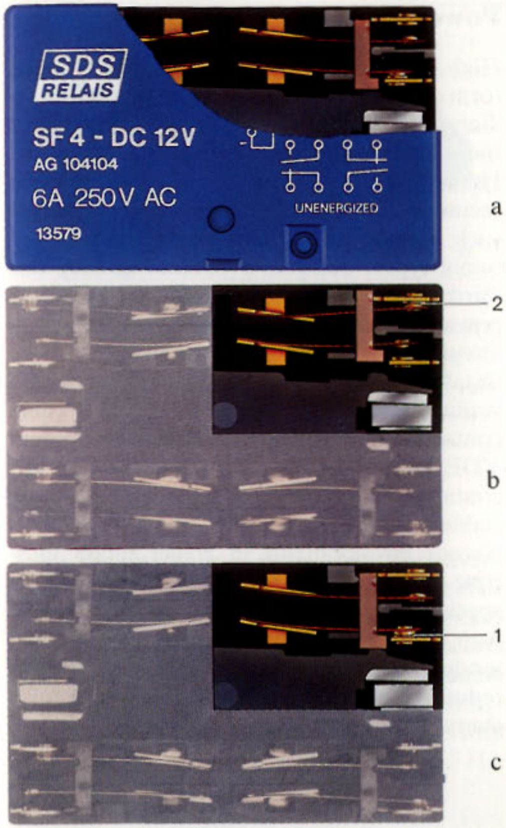


Fig. 39:
Position of the SF-relay contacts a) in the de-energized condition; b), with an outer contact 2 welded; and c) with an inner contact 1 welded

mally open contact. If, for example, the normally open contact is closed, then the normally closed supervision contact must be open, and vice versa. Forced-contact operation of one contact to the other ensures that the relay will drop out even when all contacts of the circuit to be safeguarded have welded. An example on page 50 shows a polarized, monostable safety relay type SF (Safety First). It has a new type of forced-contact operation, which complies with the highest safety specifications (e. g. ZH 1/457).

Forced-contact operation

Power Relays

High switching capability in a small package

High-load-switching relays are available in the form of power relays, miniature relays or auxiliary contactors *(mini contactors)*. As a rule, they switch in excess of 10 A, at 240/415 V. Here too the part functions described in the second chapter can be utilized. Fig. 40 shows such a relay which, compared with conventional types, occupies a volume of only one third and consumes only one fifth of the power. Further, if the C switching circuit is integrated, only approximately one thousandth of the power consumption of conventional type is needed. In the MC (mini contactor) built to German electrical standard VDE 0660, there are four contacts. The MC contactor is available in monostable or bistable versions (fig. 41 a).

Recent developments in power relays illustrate how modern relay technology can be applied to types for PCB use or for switching with either the C switching circuit or the VS-module, so that either power consumption is reduced from 500 to 2 mWs, or stepping relay characteristics are achieved.

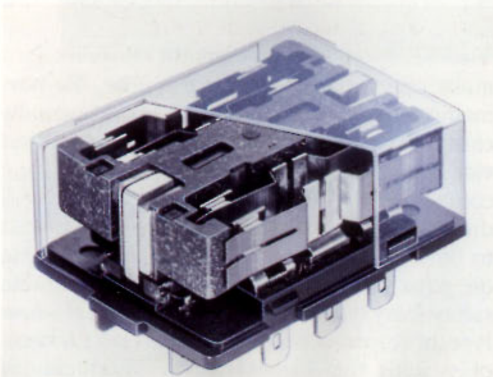


Fig. 40: SP-relay which can switch 10^{-4} to 4000 VA on two or four changeover contacts yet consumes only 0.3 W

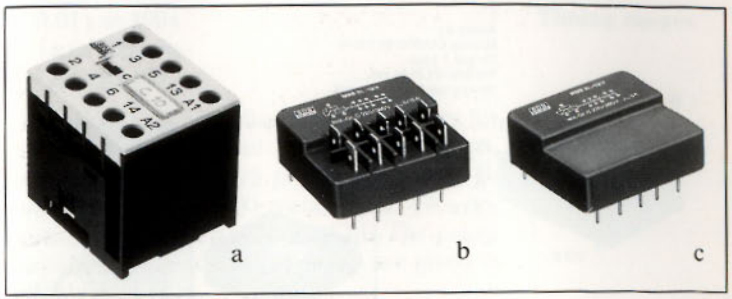


Fig. 41: The development of polarized mini contactors (SDS mini contactor type MC; 45.2 × 40 × 45 mm) to the monostable, bistable (latching) or tristable pcb-safety relay types b and c (45.2 × 40 × 18 mm)

Time-Delay Relays

There is a multitude of time-delay relays available. These have their time period set either analogously via a potentiometer, or digitally via an encoder switch. PCB time-delay relays type TR and TS, which are available for timing ranges up to 10, 100, or 800 seconds for either On-delay or Off-delay or as pulsing relays with adjustable frequency between 0.004 and 5 Hz, find a wide range of application.

Universal load-switching ranges

The TR type is based on the R relay (see illustration on the title page). The TS type incorporates the S relay, which has a total of four contacts (fig. 34, 2NO2NC, 3NO1NC, 4NO) and can switch all loads ranging from 10^{-10} to 1000 VA. No auxiliary voltage is required for the Off-delay versions. Both types are easily adjusted, even when mounted on PCB, and are immune to external interference. They offer highly accurate repeatability.

Universal time-delay ranges

Another example of a high accuracy time-delay relay having a time elapse visual display for use in the range of 0.1 s to 100 h 39 min is

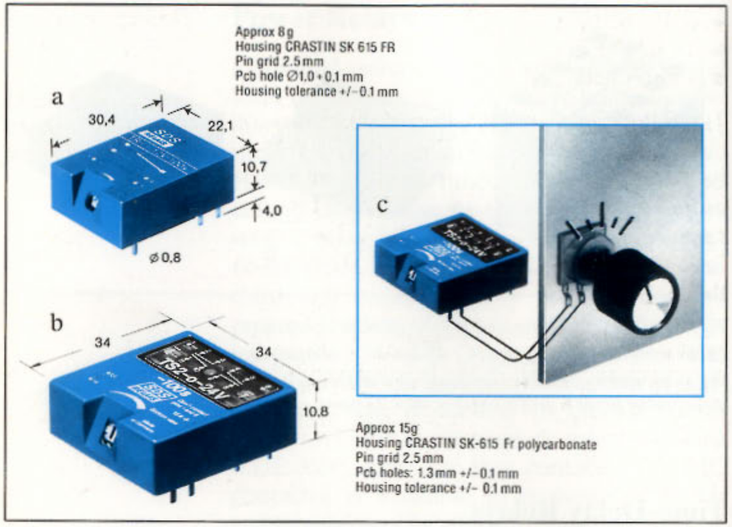


Fig. 42: SDS time delay relays type TR (a), TS with inbuilt potentiometer (b) and TS with external potentiometer (c) for timing ranges 1 . . . 1000 seconds

the QM 48. This time-delay relay is available for operation on 12 to 110 Vdc or up to 240 Vac. Being quartz controlled, it can switch up to 8 A, 2 kVA max. in ON-delay mode. The digitally set reference time and the time elapsed display are adjustable in the ranges:

Fig. 43: Quartz controlled high precision time delay relay for timing 0.15 sec to 100 hours with the same relay

Timing ranges

- 0.01 s to 100 s
- 1 s to 100 min
- 1 min to 100 hrs

The following is an indication of the prices for high-quality, advanced time delay relays, based on the 1987 SDS price list, and for an order quantity of 1000 pieces Type TR – approx. £ 12. Type TS approx. £ 14. The prices for the QM 48 and its accessories are given in the table below:

Quantity	1	5	20	50	100
QM48-DC 12 ... 110 V	61.58	56.84	55.98	54.33	53.54
QM48-AC115 and 240V	61.58	56.84	55.98	54.33	53.54
Socket AT8-RFD-Q	3.51	3.38	3.19	3.04	2.63
Plug AD8-RC	0.62	0.56	0.54	0.50	0.45

Table 5: Time delay relay and accessory costs in £ per piece using the example of the SDS type QM 48

High-Frequency Relays

HF relays switch signals such as those occurring in TV aerials, video equipment, HF measuring instruments and radio systems. The range of high frequency (HF) extends over approximately 10 MHz to 1 GHz. The following characteristics are of particular importance:

Characteristics of high frequency relays

Cross-talk attenuation is the ratio of an unintentionally coupled signal value to the original.

Due to capacitance, HF signals can pass from one circuit to an adjacent one, even with contacts opened. The larger the value of the cross-talk attentuation, the better.

Insertion loss is the ratio of input to output power. The insertion loss arises from losses due to line inductances, resistances, capacitive shunts, and mismatching. Insertion loss should be as small as possible.

The *matching attenuation* characterizes the ratio of the incoming HF power to the reflected power. The larger this ratio, the better the matching of the relay to the source of the HF signal, and the less HF power will be reflected.

The *voltage standing wave ratio (VSWR)* results from the voltage maximum and minimum if, due to mismatching, transmitted and reflected signals superimpose. If there is no reflection then the VSWR is 1.

Structure of an HF Relay
Fig. 44 shows an exploded view of a high frequency relay type RK from SDS.
The main body moulding (1), incorporates an earthed shielding chamber (2) and the fixed contacts (3). The drive mechanism (4) consists of a coil (5) and a parallel guided armature (6). Contact actuators (7) have bridge contacts (8) attached to them. The cover (9) is sealed to the main body by means of a potting compound. As shown in the circuit diagram, the contact springs (8 and 8′), configured as bridge contacts, are also earthed when open.
Table 6 lists significant data for three different SDS HF relay types at maximum frequency of the switched load.
The TQ is a universal relay which, for HF applications, is provided with a shielded cover. The relay type RG is suitable for use as an antenna switch-over relay. With a characteristic impedance of 75 ohm, it can be used in video technology, and with a characteristic impedance of 50 ohm, it can be used in HF measuring technology. The relay type RK is the most modern development of its kind.

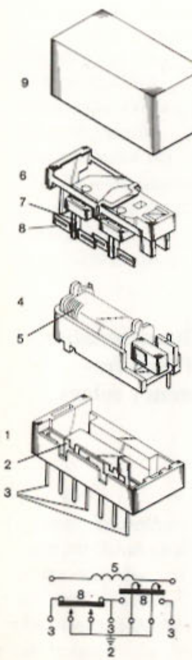


Fig. 44: Construction of a modern HF-relay (illustrated, the RK-relay from SDS)

Relay type	TQ 	RG 	RK 
Dimensions (l x w x h)	14x9x5	25x19(23)x10.4	20.2x11.2x9.7
Contact type	2CO	1CO(2CO)	1CO
Switched load	50 VA	25 VA	0.25 VA
Operation range	< 100 MHz	< 1 GHz	< 1.3 GHz
Isolation loss	40 dB	> 65 dB	> 60 dB
Insertion loss	0.1 dB	< 1 dB	< 1 dB
Return loss	> 35 dB	> 25 dB	> 10 dB
VSWR	1 dB	< 2 dB	< 1.8 dB

Table 6: The major significant characteristics of modern HF-relays; dimensions in mm

Miniature Relays of Today

The universally applicable TQ relay is a good example of a modern relay. It has a friction-free armature mounting, making the relay highly shock and vibration-resistant. It is available in both monostable and bistable (latching) versions. Gold plated crossbar bifurcated linear contacts guarantee high reliability with

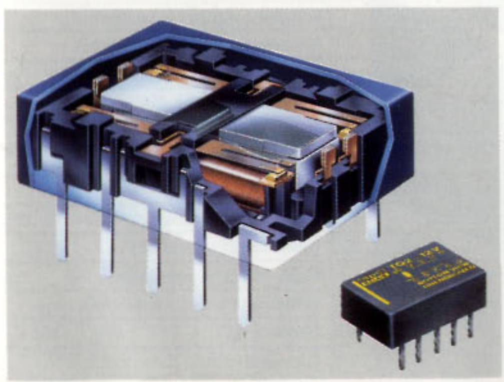


Fig. 45: The world's smallest universal relay type TQ from SDS shown full size (below)

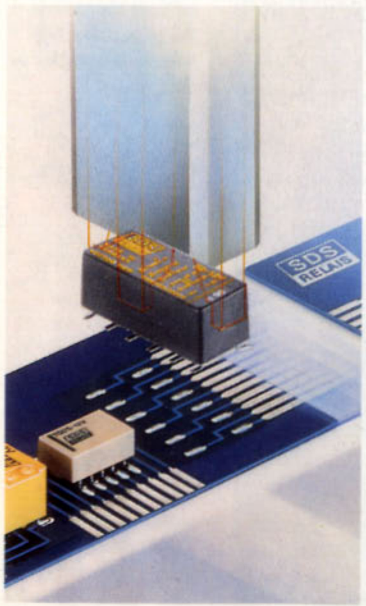
HF suitability

long life. The low contact capacitance of approximately 0.5 pF is a major feature for the HF suitability of the TQ. The squat contact structure results in a small self-inductance and hence, a high self-resonant frequency. The TQ relay can be operated both via a C switching circuit and in conjunction with the VS-module as a miniature stepper relay. A special version with gull wing connections is suitable for all surface mounting (SMT) soldering techniques.

SMT: Mounting Technology of the Future

Fig. 46: Surface mounting of relays (illustrated types DS, TQ and S from SDS)

The concept of omitting the PCB drill-holes and directly soldering the contact connections to the PCB tracks, thus allowing components to be mounted on both sides of the PCB, has



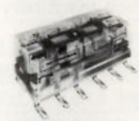
resulted in a considerable increase in system capability.
This implies:

Significance of surface mounting

- considerable space and cost savings
- higher, component-independent, mounting output with simultaneous identity and fault testing
- simplified component assembly, magazine stocking, and feeding

The critical part of this technology is soldering with its associated very high temperature stress on the relays. In addition to hot iron and laser soldering, the hot belt reflow process is often used. Suitable relays are shown in table 7. The TQ relay was specially developed for surface mounting and can therefore also be used with IR reflow, vapour phase, and double wave soldering methods.

Table 7: Characteristics of main SDS relay types for surface mounting

Relay type												
												
	DR			TQ			DS2E			S		
Dimensions l×w×h (above pcb) mm	20 x 10 x 10.2			14 x 9 x 5.2			20 x 9.9 x 11			28.4 x 12.5 x 12		
Contact configuration (NO=Normally Open NC=Normally Closed CO=Changeover)	1CO			2CO			2CO			2NO2NC. 3NO1NC. 4NO		
Volumetric-/contact resistance in mΩ	10/30			20/50			8/35			10/30		
Max.make-/continuous-/break current A	8/3/3			5/2/1			8/4/3			20/5/5		
Switched voltage range Vdc(Vac)	10^{-5}...110 (250)			10^{-3}...125			10^{-5}...250			10^{-5}...250		
Switched load range W(VA)	10^{-10}...30 (60)			10^{-9}...100 (100)			10^{-10}...90(250)			10^{-10}...100(1000)		
Pick-up/drop-out/bounce time ms	Approx 1.0/0.5/0.4			3/2/1			3/2/1			8/5/1	9/5/2	10/5/2
Switching configuration	mono-	bistable		mono-	bistable		mono-	bistable		mono-	bistable	
Number of coils	1	1	2	1	1	2	1	1	2	1	1	2
Nominal voltage types VDC (VAC)	3-24	1.5-24	3-24	3 – 48			1.5 – 48			3-48	1.5-48	
Power consumption at 12 V mW	103	63	119	140	100	200	140	70	140	200	100	200
Shock-, Vibration resistance g, g/Hz	100, 20/2000			50, 20/55			50, 20/2000			50, 20/1000		
Voltage withstand contact-/contact-coil V_{rms}	750/1500			750/1000			1000/1500			750/1500		
Efficiency η_L	938	1876	938	2720	3870	1900	3685	7370	3685	5700	13300	5700
Price each for 1000 pieces excl. VAT £	1.77	1.94	2.25	1.93		2.05	1.92	1.98	2.03	2.98	3.18	3.49

Relay Applications

The success of electrically controlled equipment and systems is influenced by the correct choice and application of switching elements, both of which require expert knowledge of the operating characteristics. While table 4 (page 45) illustrates major technical and economic differences, table 8 (below) clearly illustrates the wide range of application for relays. This applies in particular to relays of the 2nd and 3rd generation.

Relays everywhere?

in Measurement / Control / Regulation of	Temperature			Humidity			Gases			Light			Pressure			Weight			Time			Speed			Acceleration			Length			Power			Noise			Impulse			Current			Voltage			Resistance			Frequency			Field strength			Rays			Level			Program flow		
Relay generation	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Communication																					•											•		•	•			•	•		•			•			•			•	•								•	•		•	•
Supervision systems		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•
Signalling systems		•								•	•								•	•	•		•	•					•	•				•	•			•	•																						•	•	•
Remote control systems		•			•			•			•			•			•			•			•			•						•			•			•			•			•			•			•			•			•			•			•	
Lighting		•	•							•	•	•							•		•									•																																•	•
Medical technology		•	•		•	•		•	•					•			•			•	•																	•	•		•	•		•	•		•	•		•	•					•			•			•	•
Analysis equipment		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•					•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•
Test equipment		•	•								•			•			•		•	•	•										•	•							•	•	•	•	•	•	•	•	•										•	•		•	•	•
Optical systems		•	•								•	•								•	•		•	•					•	•		•						•	•																	•	•						
Office machinery		•									•									•	•																			•	•		•	•			•																	•	•
Computers																																						•			•			•																			•	•
Domestic equipment	•	•								•	•									•	•																			•	•		•	•																		•	•
Toys										•	•	•							•	•		•																•			•			•																		•	•	
Entertainment electronics	•									•									•																•	•		•	•		•			•			•			•													•	
Robots												•		•	•		•	•			•								•	•		•	•		•	•				•	•		•	•			•	•		•	•					•	•		•			•	•
Automation	•	•								•			•	•		•	•		•	•	•	•	•					•			•	•						•	•	•	•		•	•																		•	•
General installation syst.	•	•		•	•		•	•		•	•		•	•		•	•		•	•	•	•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•													•	•	•
Machinery	•	•											•	•	•	•		•	•	•	•		•									•	•								•	•		•	•		•	•		•	•						•	•		•		•	•	•
Aerospace		•	•		•	•		•	•		•	•		•	•					•	•		•	•		•	•					•	•					•			•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•
Military engineering		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•	•		•			•			•			•			•			•	•		•	•		•	•		•	•		•	•
Power stations		•									•			•						•	•		•									•						•		•	•		•	•		•	•		•	•					•	•	•		•	•	•	•	•
Water supply	•	•		•	•		•	•					•	•					•	•		•									•									•			•			•											•	•	•	•	•
Mining/Tunnelling		•		•	•			•			•			•			•			•	•		•																	•			•			•			•																
Traffic systems	•	•			•			•			•			•						•	•		•			•						•			•					•	•		•	•		•	•			•										•			•	
Transportation equipment													•	•		•	•		•	•	•	•	•					•	•			•									•	•		•	•		•	•														•	•	•

Table 8: Selected applications of 1st, 2nd and 3rd generation relays. Across the table, the physical quantities are given which can be measured, controlled or regulated by relays. The vertical column gives the range of application. Comparison with a similar table published approximately eight years ago shows a particularly strong growth in the application possibilities of 2nd and 3rd generation relays.

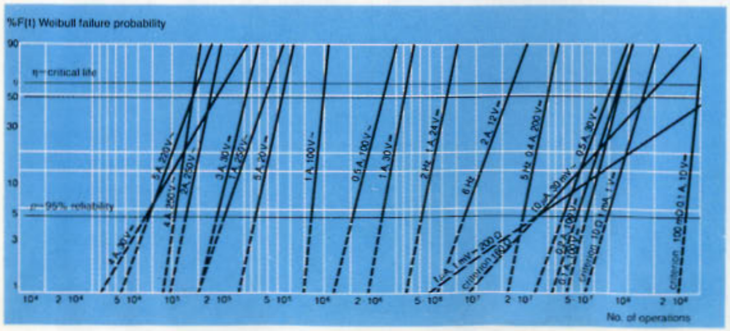
Reliability of Relays

The implication of "reliability"

Reliability is a component of quality, measured in terms of time. It expresses the probability of a relay continuing to meet specified requirements for a given period of time.
The economical operation of equipment and components does not start until a certain reliability is achievable. Excessive requirements for reliability generally prove to be uneconomical. The success of an enterprise is therefore significantly influenced by the correctly monitored reliability requirements of the component.

It should be generally understood that the main features affecting relay reliability are contact resistance which should be small and constant, and a low tendency of contact bounce. Examples of such contact resistance are illustrated in the test results displayed in fig. 16, and their analysis on page 21.
At first consideration it may seem plausible to measure reliability, under all imaginable conditions, in terms of operational life. However, in practice it is not realistic to state the average life for all switching loads and different environmental influences. For this reason, in many cases, it is decided to publish a *Weibull diagram* (fig. 47) for resistive load switching ranges. In the example, the life of the S relay is shown for loads from 1 nW (which corresponds to 1 μA at 1 mV) up to 1 kVA (4 A, 250 V AC) at normal ambient temperature. The steeper the Weibull lines, the less scatter in the life values of individual relays. For inductive or capacitive load switching, the appropriate current and voltage peaks must be taken into account.
If the Weibull diagram does not show a load which corresponds to the requirements, or, in the event of additional stresses (e. g. raised temperatures), life tests under operational conditions are necessary at the maximum permissible switching frequency.

Fig. 47: Weibull reliability data for the S-relay from SDS. Failure criterion: contact resistance > 100 mΩ unless stated otherwise



What does a Weibull diagram show?

Reduction in rejections

Reliability is further reflected in the number of complaints and rejections received. A sudden drop in rejections implies that an effective step forward has been taken in the direction of increased reliability. An example of this is the use of getters in all R relays manufactured since 1976. This shows (fig. 48) that the bifurcated linear contacts of R relays, (already 50 times more reliable than single contacts), could be improved yet further "at a stroke".

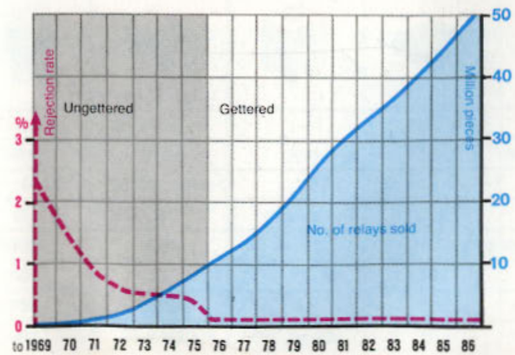


Fig. 48: Pattern of rejection rates of ungettered and gettered relays between 1969 and 1986. In 1975 the changeover to gettering took place.

Economic Considerations

Savings of £ 11 billion possible

The outstanding developments made in relay technology will not be totally understood until an evaluation of relay efficiency is made, and until the relationship between performance and cost is recognized. Such a study was carried out in 1982, and concluded that there were potential savings for the German economy of approximately 33 billion Deutsch marks (£ 11 billion) if instead of the approximately 1 billion 1st generation relays used in the Federal Republic of Germany, 2nd and 3rd generation relay types were installed instead. The cost analysis for 1982 is illustrated in fig. 49.

Nowadays, after 5 more years of development and expansion in safety relays, power relays, contactors and HF relays for telecommunications, and furthermore with the state-of-the-art products currently available on the market (that would not be possible without modern relay technology), the potential savings are even higher than shown in the 1982 study.

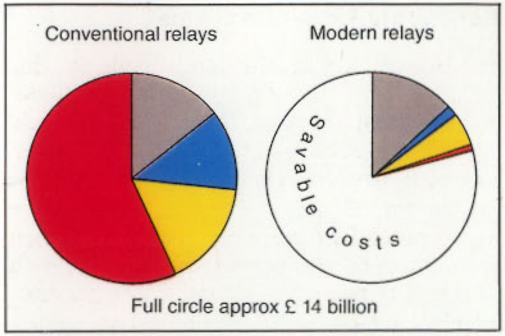


Fig. 49: Estimated cost analysis of a billion conventional and modern relays. The possible cost savings are shown in brackets. The colours represent the following:
- *Manufacture DM 0.5 billion (£ 0.2 billion)*
- *Power consumption DM 4.65 billion (£ 1.5 billion)*
- *Storage and transport DM 4.5 billion (£ 1.5 billion)*
- *Failure costs DM 23.8 billion (£ 8 billion)*

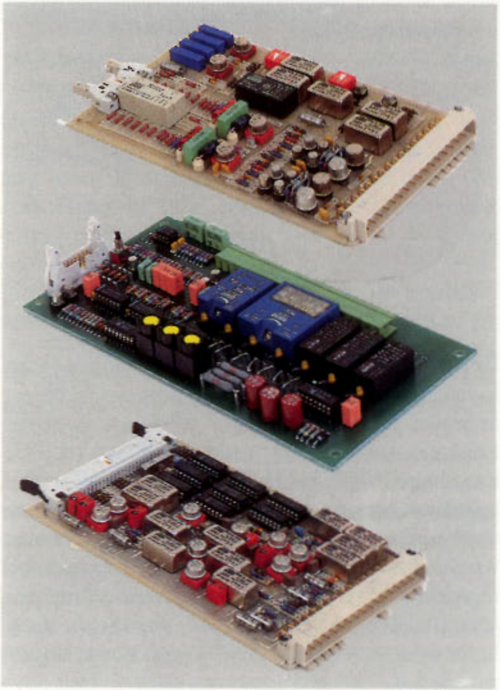
In that study, the costs of a relay failure in an industrial application were estimated to be on average 800 DM (£ 270). With an average rejection rate for conventional relays of 3%, the result was 24 DM/relay (£ 8). With the rejection rate reduced to 0.004% due to gettering, the amount which now would result would be 0.032 DM (£ 0.01). It should be remembered that there are conventional relays which, to some extent, show an even higher degree of reliability, such as is demanded by the aerospace industry.

Relay type		Example 1		Example 2		Example 3	
		Bistable relay		Stepper relay		Adjustable time-delay relay	
							
Type - No of contacts		*) – 4	TQL – 4	HCR – 4	VS+S2L2-3	*) – 4	TS – 4
Volume - relay generation	cm^3-n	6.5-1	0.6-2	26-1	3.9-3	20-1	12.3-3
Load switching range	VA	+)...30	10^{-9}...100	10^{-5}...500	10^{-10}...1000	+)...60	10^{-10}...1000
Pick-up (delay) time	ms (s)	10	3	18	8	(0.1...120)	(0.1...800)
Voltage withstand contact/earth	V_{rms}	500	1000	1500	1500	1000	1500
Power consumption	W	0.85	0.1	3.5	0.2	1	0.24
Efficiency at 10^5 sw. ops.		22	3810	77	3850	3.5	1350
Price each for 1k pcs	£	approx 3.80	1.94	7.00	4.80	140 approx	12

Table 9: Power-/price comparison of three 1st generation relay types with equivalents from the 2nd and 3rd generation.

**) Not stated due to restrictions on naming competitors*
+) No manufacturers information

Fig. 50: Application of modern relays. Shown here on converter pcb



Modern relays up to 13 times lower in cost

Example 3 in table 9 shows such a relay which, at approximately £ 140, is thirteen times more expensive than the comparable 3rd generation TS relay produced with the new technology. It must be remembered, however, that newly introduced relays are generally subject to a much higher rejection rate.

Quality and performance have their price, but if more output and higher quality are generally offered at a lower price, then these are "evolution indicators", which justify a classification into generations, i.e. in performance categories. Table 9 provides a comparison of 3 different types of 1st generation relays with relays of the 2nd and 3rd generation. A further example is given in table 4 (page 45).

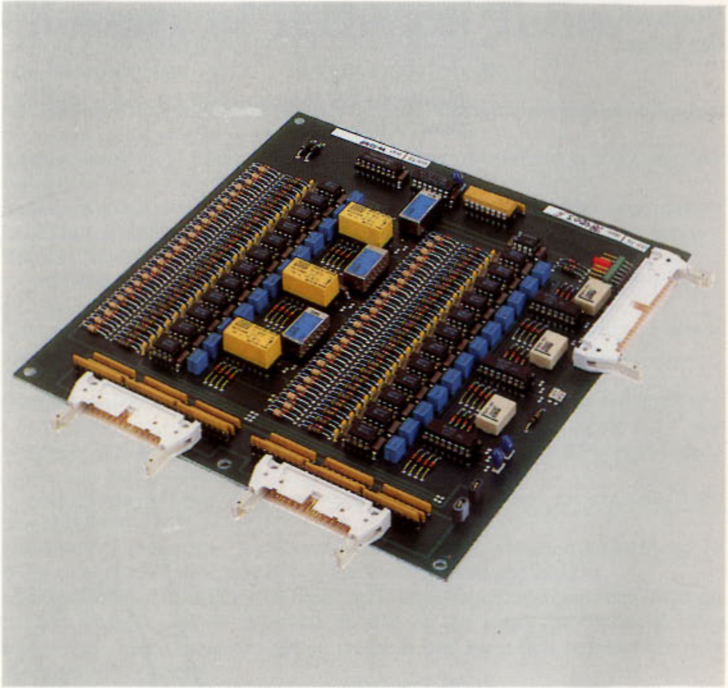


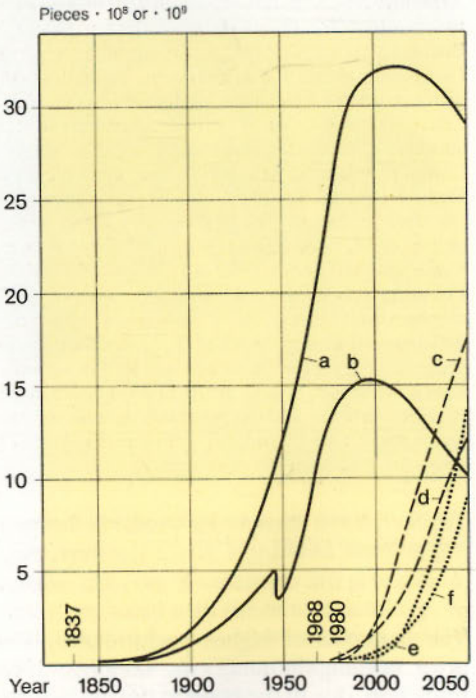
Fig. 51: Pcb with relays for high sensitivity automatic test equipment (ATE)

Modern relays in the electronic age

The demands of higher performance, lower price, and higher quality are no longer a contradiction, due in the main to the development of new technologies and economic methods of production. Relays which, in spite of intensive miniaturisation can offer increased performance, cost less, and operate in an energy efficient and reliable manner, certainly have a good future. Fig. 52 predicts the worldwide utilization of this knowledge, which itself has been developed due to flexibility. The forecasts are based on:

Prognosis for the future

- statistical collation of relays manufactured
- an estimated average relay life of 14 years
- the characteristics, costs, and potential applications for relays of the 1st, 2nd, and 3rd generation.



— a 1st generation relays since 1837, Worldwide · 10^9 pieces
— b 1st generation relays since 1837, Central Europe 10^8 pieces
– – c 2nd generation relays since 1968, Worldwide · 10^9 pieces
– – d 2nd generation relays since 1968, Central Europe · 10^8 pieces
······· e 3rd generation relays since 1980, Worldwide · 10^9 pieces
······· f 3rd generation relays since 1980, Central Europe · 10^8 pieces

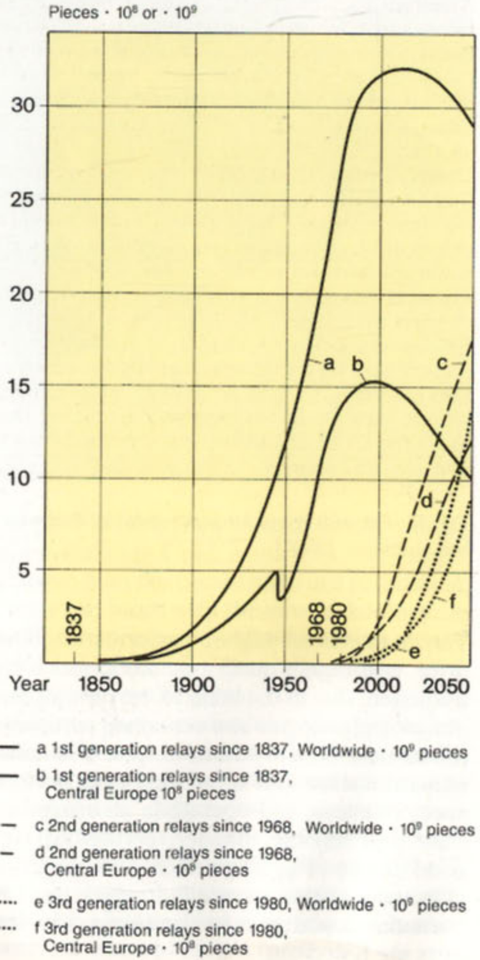
Fig. 52: Estimated growth in relay use over two hundred years

Glossary of Technical Terms

AC relays are operated in the 50–60 Hz range. They are less important for low current or signal switching applications.
Ampère turns (AT) The product of the number of windings in a coil and the strength of the current flowing through the coil (magnetic flux).
Armature is that part of a relay which is moved by electrical/permanent-magnet forces into different positions and opens or closes contacts during this action.
Bistable (latching) relays have two stable switched positions.
C-switching circuit Capacitor circuit which limits the power consumption to the pick-up time (0.5 to 10 ms) of the relay.
Change-over contact, when actuated, opens one contact path and closes another.
Contact configuration describes the type and number of contacts.
Contact reisistance should be as small as possible (< 25 mOhm) and constant, i.e. free from any film, where dry loads with a voltage below 0.1 V are switched. When switching high current (> 5 A) it must be even lower to reduce power loss and heating.
Counting relays have, as a rule, a stepping mechanism for counters with numbers from 0 to 9.
Efficiency of a relay must be life-related for a specific switched contact load, in order to be a valid indicator of quality for a specified application.
Film resistance is caused by the build-up of high-impedance contaminations on contact surfaces and is regarded as one of the major problems in relay technology. Use of suitable getter methods can keep film resistance at low levels for long periods.
Forced-operated contacts exist in a relay, if synchronous switching is ensured even in fault conditions (e.g. welded contacts).
Gettering is used in vacuum technology to increase the vacuum. In relay technology, it is a method of binding molecules of foreign matter to the permanent magnet surface which has been activated into a getter, in order to prevent films of foreign matter forming on the contacts.
Holding current is the minimum coil current which holds the armature in the operated condition. As a rule, it is approx. 30% of the pull-in current, so that in conventional arrangements, appropriate economizing circuits were provided. By using the C-switching circuit, the holding current corresponds to the leakage current of the capacitor of < 0.1 mA or 0.01% of the pull-in current.
IC relays represent a symbiosis of solid state technology with modern relays, intended to provide additional or programmable functions, whilst saving space and energy.
Mercury wetted relays use mercury as the contact material.
Monostable relays have a definite rest position in the non-energized state.
Non-polarized (neutral) relays operate independently of the direction of the energizing current.
Normally closed contact opens when the relay is energized
Normally open contact closes when the relay is energized

Prognosis for the future

- statistical collation of relays manufactured
- an estimated average relay life of 14 years
- the characteristics, costs, and potential applications for relays of the 1st, 2nd, and 3rd generation.



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Polarized relays are available in monostable, bistable, or tristable versions. Their operation is dependent on the current direction. In applications with the same voltage polarity, monostable relays fulfill all the functions of non-polarized relays, but with lower power consumption.
Reliability is the most important characteristic of relays.
Remanence relays remain in the switched position, due to residual magnetism in the magnetic circuit, even after excitation has ceased. Polarized relays perform the same function but much more reliably and economically.
Semiconductor relays have no mechanically operated contacts, but switch the current by means of semiconductor elements, such as triacs, thyristors, or power transistors.
Stepper relays change their switched position due to pulses of the same polarity.
Three-position contactor – a high-performance relay with three switch positions, the centre position being contactless.
Time-delay relays switch after expiry of a predetermined period of time.
Vacuum relays contain contacts in a high vacuum for switching voltages up to 50 kV.
Wear – Loss of material on contacts due to switching arcs.
Weibull diagrams are used for statistical statements of reliability of components which are subject to wear. They show the number of failures in relation to the number of switch operations, against defined application and failure criteria.
Wiping relays operate one or more contacts briefly during the action of switching ON or OFF.
Yoke is a soft magnetic flux conducting plate and is the magnetic bridge between coil core and relay armature.

Additional Reading

Modern Relay Technology ed. by Hans Sauer, Heidelberg 1986. Published by Dr. Alfred Hüthig Verlag, 367 pages, 410 illustrations, 50 tables, 240 relay types, ISBN 3-7785-1251-X.

DABEI-Handbuch für Erfinder und Unternehmer (Handbook for Inventors and Entrepreneurs). Only available in German; publ. by the Deutsche Aktionsgemeinschaft Bildung-Erfindung-Innovation e. V., Friedrich-Ebert-Allee 39, 5300 Bonn 1. (With this book, fifteen successful and well-known inventors and entrepreneurs and more than a hundred recognized experts in relevant sectors have created a work which is unique in many respects. Contents: Education, Training – Self-Recognition and System Recognition – Cybernetics, Bionics (Methods of Invention) – Technical Progress by Cooperation – Inventing – From the Problem to the Product – Utilizing Technical Information – Protection of Industrial Property – Innovation – Things of note – Design and Standardisation – Commercial Law – Founding a Company – Contracts – Competition – Succession – Market Research, Marketing – Outline Conditions – Tax Law for Inventions – Interrelations of National Economies – The Adventure of Inventing – Inventors – Companies – Short Stories – Useful Addresses of Institutes – Award for Inventors – Technologies of the Future – Concise Encyclopaedia – Explanations, Information, Views. DABEI Members (Membership Subscription DM 100.00 p. a.) receive a DABEI Handbook as a working aid, free of charge. Obtainable from bookshops or from the VDI Verlag at a price of DM 148.00.

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